PB81-197089

Methodology to Conduct Air Quality Assessments of National Mobile Source Emission Control Strategies

Energy and Environmental Analysis, Inc.
Arlington, VA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Oct 80

U.S. Department of Commerce
National Technical Information Service
NTIS

PB81-197085

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/4-80-026
October 1980

Air

EPA

Methodology To Conduct Air Quality Assessments of National Mobile Source Emission Control Strategies

Final Report

PRODUCT OF:
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 450/4-80-026	2.
3. RECIPIENT'S ACCESSION NO. PB81 197089	
4. TITLE AND SUBTITLE Methodology To Conduct Air Quality Assessments of National Mobile Source Emission Control Strategies	5. REPORT DATE October, 1980
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James H. Wilson, Jr., Mark A. Scruggs	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Energy and Environmental Analysis, Inc. 111 North 19th Street Arlington, Virginia 22209	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-02-3371
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Protection Agency Research Triangle Park, North Carolina 27711	13. TYPE OF REPORT AND PERIOD COVERED Final
	14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES EPA Project Officer - Warren P. Freas	

16. ABSTRACT

This report describes a methodology for conducting air quality assessments of national mobile source emission control strategies using the Modified Rollback Model and standard EKMA isopleths. Both modified rollback and EKMA are simple models which do not require extensive data bases. As such, they are most useful for estimating the impact of an emission control strategy on air quality in nationwide studies where a number of alternative control strategies must be analyzed in a great many areas. Recommended methodologies and data assumptions are consistent with those used in the regulatory impact analyses for alternative national air standards for ozone and carbon monoxide.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Mobile Sources Air Quality Analyses		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 100
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-450/4-80-026

Methodology To Conduct Air Quality Assessments of National Mobile Source Emission Control Strategies

Final Report

Energy and Environmental Analysis, Inc.
1111 North 19th Street
Arlington, Virginia 22209

Contract No. 68-02-3371

EPA Project Officer: Warren P.G. Freas

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

October 1980

This report was furnished to the Environmental Protection Agency by Energy and Environmental Analysis, Incorporated, 1111 North 19th Street, Arlington, Virginia 22209, in fulfillment of Contract No. 68-02-3371. The contents of this report are reproduced herein as received from Energy and Environmental Analysis. The opinions, findings and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency.

Publication No. EPA-450/4-80-026

TABLE OF CONTENTS

		Page
1	INTRODUCTION	1-1
	1.1 Purpose of this Report	1-1
	1 2 Past Applications of Rollback and EKMA	1-2
	1.3 Report Organization	1-4
2.	APPLICABILITY OF ROLLBACK AND EKMA	2-1
	2.1 Assumptions and Limitations	2-1
	2.1 1 Rollback Assumptions	2-1
	2.1.2 Rollback Limitations	2-4
	2 1 3 EKMA Assumptions	2-5
	2.1.4 EKMA Limitations	2-6
	2.1 5 Applications of EKMA to Ozone Strategies	2-8
	2.2 Use in Nationwide Studies	2-11
	2.2.1 Carbon Monoxide	2-11
	2.2.1.1 Applicability of Rollback	2-12
	2 2.1.2 Comparison of Results Using Rollback and the Indirect Source Guidelines	2-14
	2.2.2 Ozone	2-15
	2.2.3 Nitrogen Dioxide	2-16
3.	SUGGESTED METHODOLOGIES FOR COMPILING MODELING DATA	3-1
	3.1 Emission Inventories	3-1
	3.1.1 Ozone	3-1
	3.1.2 Carbon Monoxide	3-9
	3.1.3 Nitrogen Dioxide	3-10
	3.2 Design Values	3-14
	3.2.1 Carbon Monoxide	3-17
	3.2.2 Ozone	3-17
	3.2.3 Nitrogen Dioxide	3-18

TABLE OF CONTENTS (Continued)

		Page
3.3	Growth and Retirement Rates	3-20
3.3.1	Stationary Sources	3-20
3.3.2	Mobile Sources	3-23
3.4	Control Effectiveness	3-30
3.4.1	Mobile Sources	3-30
3.4.2	Stationary Sources	3-32
3.5	Source Contribution Factors	3-40
3.5.1	Ozone	3-41
3.5.2	Nitrogen Dioxide	3-42
3.5.3	Carbon Monoxide	3-42
3.6	Transportation Control Factors	3-51
4.	STRATEGY EVALUATION CRITERIA	4-1
4.1	Percentage Change in Pollutant Concentration	4-1
4.2	Number of Exceedances of the NAAQS	4-2
4.3	Number of Regions with Ambient Levels Greater than the Standard	4-4
4.4	Other Strategy Evaluation Criteria	4-5
4.5	Conclusion	4-5
5.	SUMMARY AND CONCLUSIONS	5-1
5.1	Applicability of Rollback and EKMA	5-1
5.2	Suggested Methodologies for Compiling Modeling Data	5-3
5.2.1	Emission Inventories	5-3
5.2.2	Design Values	5-4
5.2.3	Growth and Retirement Rates	5-4
5.2.3.1	Stationary Sources	5-4
5.2.3.2	Mobile Sources	5-5

TABLE OF CONTENTS (Continued)

Page

5.2.4 Control Effectiveness. 5-5
5.2.5 Source Contribution Factors. 5-6
5.2.6 Transportation Control Factors 5-7
5.3 Strategy Evaluation Criteria. 5-7

1. INTRODUCTION

1.1 PURPOSE OF THIS REPORT

The purpose of this report is to (1) review and evaluate current procedures, and suggest new procedures when warranted for applying modified rollback modeling assumptions and the Empirical Kinetic Modeling Approach (EKMA) to national strategy assessments, and (2) to compile national data bases for CO, O_3, and NO_2 for use in future nationwide mobile source studies. Both modified rollback and EKMA are simple models which do not require extensive data bases. As such, they are most useful for analyzing the impact of an emission control strategy on air quality in nationwide studies where a number of alternative control strategies must be analyzed in a great many areas. While these models may not estimate absolute concentrations in each modeling region with great accuracy, they are useful for predicting the relative impacts of a number of alternative emission control scenarios on a nationwide basis.

The rollback model is based on the assumption that a change in pollutant emissions will result in a proportional change in the pollutant's ambient concentration. In its simplest form, rollback assumes that the concentration of a pollutant at any point is equal to its background concentration plus some linear function of the total emission rate of that pollutant in the area which impacts the concentration at that point. However, the version of the rollback equation discussed in this report provides for different assumptions to be included for each of a number of source categories which comprise the total emission rate of a pollutant. For instance, growth in new sources, control efficiencies, and a typical source-receptor relationship can be specified for each source category of interest. The source-receptor relationship is especially important, because it is what differentiates rollback from other more sophisticated air quality models.

EKMA is a procedure for using an isopleth diagram to estimate the effectiveness of volatile organic compounds (VOC) and/or NO_x controls on ozone concentrations. The isopleths depict the sensitivity of maximum hourly afternoon ozone to changes in non-methane organic compounds (NMOC) and oxides of nitrogen (NO_x) under meteorological conditions conducive to ozone formation. The EKMA curves have been generated using a chemical kinetic model validated and calibrated with smog chamber data (U.S. EPA, 1977).

1.2 PAST APPLICATIONS OF ROLLBACK AND EKMA

One of the first uses of rollback was to set goals for the emission reductions needed from automobiles in order to meet the National Ambient Air Quality Standards on a nationwide scale (Barth, 1970). Since that time, projection analyses using rollback and EKMA have been performed to evaluate the relative air quality impacts of revisions to the automotive emission standards, inspection and maintenance programs for autos, alternative truck regulations, alternative motorcycle emission control strategies, and high altitude emission standards. The results of these analyses have been used in environmental impact statements for EPA mobile source regulations and to supply Congress and the Administration with an assessment of the air quality impacts of alternative automotive emission standards. The most recent important applications of rollback and EKMA to nationwide studies have been the EPA regulatory analyses conducted in association with the review of ambient standards for O_3 and CO (U.S. EPA, 1979 and EEA, Inc. 1979).

Past mobile source air quality assessments have been performed using a sample of Air Quality Control Regions (AQCR's) that have ambient monitoring data which indicates either present NAAQS violations or the potential for future NAAQS violations for CO, NO_2, or O_3. The monitoring data, or design values, used to choose the AQCR's with the highest pollutant levels, are used as the base year air quality concentrations in the

rollback equation. Data on current emission levels are usually taken from the U.S. EPA National Emissions Data System (NEDS) or from emission inventories prepared by State or local air pollution control agencies. NEDS is typically used because of the consistency of data collection among regions. These data are grouped into source categories which have similar growth patterns and anticipated control potential. Assumed growth rates and control efficiencies for each source category are then applied to estimate future year emissions. The relationships between emissions and pollutant concentrations typically observed at design value monitors for each source category are taken into account in the rollback formulation so that sources that have tall stacks or are usually located far from urban area monitors are assumed to have less impact on design value monitors than mobile or other ubiquitous sources. For instance, in the recent CO regulatory analysis, point source emitters were found, through modeling, to generally have no impact on monitored CO levels in urban areas, due to monitor placement (EEA, Inc., 1979).

Assuming that the relationship between air quality and emissions observed in the base year remains the same in future years, projected emissions are used to estimate ambient pollutant levels for the year of interest. Indicators such as average percentage change in concentrations, number of cities with projected ambient levels above the NAAQS, and the total number of violations are then used to characterize how air pollutant levels are expected to change. Typically, alternative emission control options are compared using these indicators.

The EKMA isopleth curves were incorporated into the nationwide analysis procedure in 1977. These curves depict the sensitivity of maximum hourly ozone to changes in non-methane organic compounds (NMOC) and oxides of nitrogen (NO_x) under conditions assumed to be conducive to ozone formation. Past EKMA analyses performed on a nationwide basis

assumed that the NMOC/NO_x ratio is 9.5:1 in all areas, and that the effects of natural background ozone concentrations on maximum afternoon ozone levels for an urban area are offset by diminishing levels of transported ozone into the areas as controls are implemented upwind. It has also been assumed in the nationwide study applications of EKMA that NO_x levels remain constant in future years.

The information presented in this report draws most heavily from the recent regulatory impact analyses for the National Ambient Air Quality Standards (NAAQS) for CO, O_3, and NO_2. The CO rollback analysis was performed by SRI International for mobile and stationary area sources (Siddiqee, Patterson, and Dermant, 1979). The CO point source analysis using the model PTMAX was performed by EEA, Inc. as well as the cost and economic analysis for all significant CO sources (EEA, Inc., 1979). The O_3 regulatory analysis used both rollback and EKMA to forecast which areas would have O_3 levels higher than various alternative ambient standards (U.S. EPA, 1979). The NO_2 regulatory work is still in progress.

1.3 REPORT ORGANIZATION

This report is organized in four sections in addition to the Introduction. Section 2 discusses the applicability of using rollback and EKMA in nationwide studies. The assumptions and limitations of the models are presented and their use in nationwide studies is discussed separately for CO, O_3, and NO_2. Section 3 presents suggested methodologies for compiling modeling data for use in rollback and EKMA. Section 4 critiques the evaluation criteria typically used to compare different model runs. A summary of the entire report is presented in Section 5.

REFERENCES FOR SECTION 1

Barth, D. S. 1970. "Federal Motor Vehicle Emission Goals for CO, HC, and NO_x Based on Desired Air Quality Levels". J. Air Poll. Control Assoc. Volume 20.

Energy and Environmental Analysis, Inc. December 28, 1979. Regulatory Impact Analysis for the National Ambient Air Quality Standards for Carbon Monoxide. Arlington, VA.

Siddiqee, W., Patterson, R. and Dermant, A. December 1979. Methodologies to Conduct Regulatory Impact Analysis of Ambient Air Quality Standards for Carbon Monoxide. (EPA-450/5-80-006). SRI International, Menlo Park, CA. (Prepared for U.S. EPA, RTP, NC).

U.S. Environmental Protection Agency. February 1979. Cost and Economic Impact Assessment for Alternative Levels of the National Ambient Air Quality Standards for Ozone. (EPA-450/5-79-002). Research Triangle Park, NC.

U.S. EPA. November 1977. Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors. (EPA-450/2-77-021a) Research Triangle Park, NC.

2. APPLICABILITY OF ROLLBACK AND EKMA

Section 2.1 presents a discussion of the assumptions and limitations of rollback and EKMA and how these models compare with alternative air quality modeling approaches. Section 2.2 discusses the use and applicability of rollback or EKMA in nationwide studies of CO, O_3, and NO_2 concentrations. Each pollutant is discussed separately in Section 2.2.

2.1 ASSUMPTIONS AND LIMITATIONS

2.1.1 Rollback Assumptions

Air quality dispersion models are mathematical constructs that attempt to represent, with varying degrees of sophistication, the relationship between pollutant emissions and the resulting concentration of that pollutant in the ambient air. If only nonreactive pollutants are considered, i.e., those that do not undergo rapid chemical transformation to some other species, then the relationship between emissions and air quality concentrations can be represented very simply as:

$$X_o = \sum_i R_i Q_i + B \qquad (2\text{-}1)$$

where:

X_o = Base year air quality concentration. It should ideally be a measured concentration which is representative of the air quality in the region of interest during the base year. This "design value" is usually chosen to be consistent with the form of the air quality standard for the pollutant being modeled.

Q_i = Base year emission inventory for source category i. The inventory should be accurate and complete for all significant sources of the pollutant being modeled. It is usually expressed in tons/year.

B = Ambient background concentration in an area (defined as the sum of the contributions from natural emission sources within the study area and the anthropogenic and natural sources outside the study area affecting concentrations in the study area) given in the same units as X_o.

R_i = Function that relates the emission rate (Q_i) to the pollutant concentration (X_o).

For example, if the Gaussian or bivariate normal equation is assumed to be representative of the behavior of the pollutant after it is emitted, the R_i takes on the familiar form given in the traditional Gaussian models. As such, R_i is characterized as a function of source-receptor distance, atmospheric stability, windspeed and the effective height of release (stack height plus buoyant rise). An important feature of the formulation, that will be employed later in this discussion, is the linear dependence of the pollutant concentration on the pollutant emission rate, i.e., for any given set of meteorology and source-receptor configurations R_i is a constant which does not depend on changes in emissions.

When the data are not available to evaluate the function R_i, or are impractical to assemble, such as in the case with an analysis of nationwide scope, then a simplifying assumption is usually made that reduces R_i to an arbitrary constant (K). If this is done, Equation (2-1) reduces to the form:

$$X_o = K \sum_i Q_i + B \qquad (2\text{-}2)$$

where, as before, X_o and Q_i are the base year air quality and emission rate (for category i) respectively, and B is the background concentration. An alternate form would be to set $R_i = kS_i$. Then,

$$X_o = k \sum_i Q_i S_i + B \qquad (2\text{-}3)$$

where the factor S_i is introduced because it is not desirable to totally discard the effect of height of release and distance on the rate of dispersion and consequently on concentration estimates.

Air quality projections for some calendar year j can be made with suitable adjustments to the emission rates for each source category i to account for growth (G_{ij}), change in emission factors (F_{ij}) resulting from imposition of controls, dispersion characteristics (S_i) and the implementation of transportation control measures (T_{ij}). The future year projection for year j then becomes:

$$X_j = k \sum_i Q_i S_i G_{ij} F_{ij} T_{ij} + B \qquad (2\text{-}4)$$

where:

X_j = Projected air quality concentration for calendar year j.

G_{ij} = Growth factor for source category i in year j. This is a measure of the expected annual growth in the activity level for each source category.

F_{ij} = Emission factor ratio for source category i in year j. An emission factor ratio is a ratio of the emission factor of an average source in some future year to the emission factor of an average source in the base year. It is indicative of the amount of control on a source category.

S_i = Source contribution factor for stationary source category i. This factor accounts for the relative effect of emission height and distance from the source to the receptor on ground level air quality. An elevated source would be expected to contribute less to ground level air quality than a ground level source under most meteorological conditions.

T_{ij} = Transportation control factor, if applicable, for mobile source category i in year j. This factor is used only to account for measures designed to reduce vehicle miles traveled in an urban area.

It has also been assumed that future background concentrations are the same as in the base year and the proportionality constant (k) is unchanged. The assumption on background invariance is not necessary and a different background estimate could be used.

The projected air quality can be estimated simply by solving Equation (2-3) for the unknown constant k and substituting that result into Equation (2-4). The resulting expression for "modified" rollback then becomes:

$$X_j = \frac{(X_o - B)}{\sum_i Q_i S_i} \sum_i Q_i S_i G_{ij} F_{ij} T_{ij} + B \qquad (2\text{-}5)$$

It is clear from Equations (2-4) and (2-5), that once the functional form of R_i is chosen (in this case kS_i) and evaluated, all strategy evaluations for nonreactive pollutants become rollback analyses. Projected air quality estimates are made by adjusting emission rates appropriately to reflect the desired emission revisions. Note also, that the rollback formulation is inherently designed to estimate changes in air quality concentrations based on current air quality and assumed background levels resulting from emission changes. As such it can only be used in the relative rather than the absolute sense.

2.1.2 Rollback Limitations

The limitations of simple rollback have previously been described (deNevers and Morris, 1975) but will be reiterated here for completeness along with additional limitations specific to air quality assessments of national mobile source emissions strategies. Obviously, rollback is an attractive methodology to employ because of its computational and resource economy. The most significant limitations are:

1. Lack of model validation.
2. The assumed linear relationship between emissions and air quality. Deposition, agglomeration and chemical reaction could invalidate the linear assumption.

3. Estimates can only be made at existing monitoring sites. If the existing monitoring data have not detected the "true" maximum concentrations, then projected air quality estimates may be understated.

4. The growth factor used assumes all other parameters remain unchanged, i.e., all sources grow equally and their spatial distribution remains constant.

5. Simple and "modified" rollback assume that the meteorological conditions occurring when the design value was measured are the same in the projection year.

6. Very simplistic treatment of source-receptor relationships.

7. Simple rollback assumes all sources emit at the same height and "modified" rollback assumes sources within certain categories emit at the same height.

2.1.3 EKMA Assumptions

While the rollback model has been widely used as a method for estimating changes in air quality levels due to changes in CO emissions and NO_2 area source emissions (see Section 2.2.3), the relationship between ozone concentrations and hydrocarbon emissions is very complex and renders the linear relationship invalid. (This is discussed further in Section 2.1.5). Hence, the EPA is currently recommending a different modeling methodology called the EKMA. Because EKMA has been described in detail (EPA, 1977) only a brief discussion follows.

EKMA utilizes a set of ozone isopleths which depict maximum afternoon concentrations of ozone downwind from a city as a function of initial (i.e., morning) concentrations of NMOC and NO_x, NMOC and NO_x emissions occurring later in the day, meteorological conditions, reactivity of the precursor mix, and concentrations of ozone and precursors transported from upwind areas.

EKMA is best used to determine the sensitivity of maximum hourly ozone concentrations observed within or downwind of a city to changes in ambient levels of NMOC and oxides of nitrogen (NO_x) precursors. EKMA is most suitable for addressing questions like, "How much reduction in local prevailing precursor levels would be needed to attain the 0.12 ppm standard for ozone" or, "What reduction in ozone levels is likely to accompany a specified reduction in precursor levels?" The method is not suitable for estimating the impact of strategies which result in substantial changes in source configurations or for questions about what the impact of controlling a single or small group of sources would be. As such, EKMA can be used in nationwide studies for the same scenarios as rollback.

There are two variations of EKMA. The first involves the use of city-specific ozone isopleths. The second utilizes a standard set of ozone isopleths in which fixed assumptions have been made about sunlight intensity, atmospheric dilution rate, reactivity and diurnal emission patterns. Because of their ease of use in a nationwide study, the standard set of ozone isopleths was used in the ozone regulatory analysis (EPA, 1979). The application of EKMA used in the ozone NAAQS regulatory analysis assumed the same NMOC/NO_x ratio for all cities. Based on an examination of data from a number of monitoring sites a median ratio of 9.5:1 was chosen. In addition, it was assumed that NO_x emissions remain constant between the base year and the projection year. The EKMA standard isopleth curves are illustrated in Figure 2-1. A line depicting the 9.5:1 NMOC/NO_x ratio is shown for reference.

2.1.4 EKMA Limitations

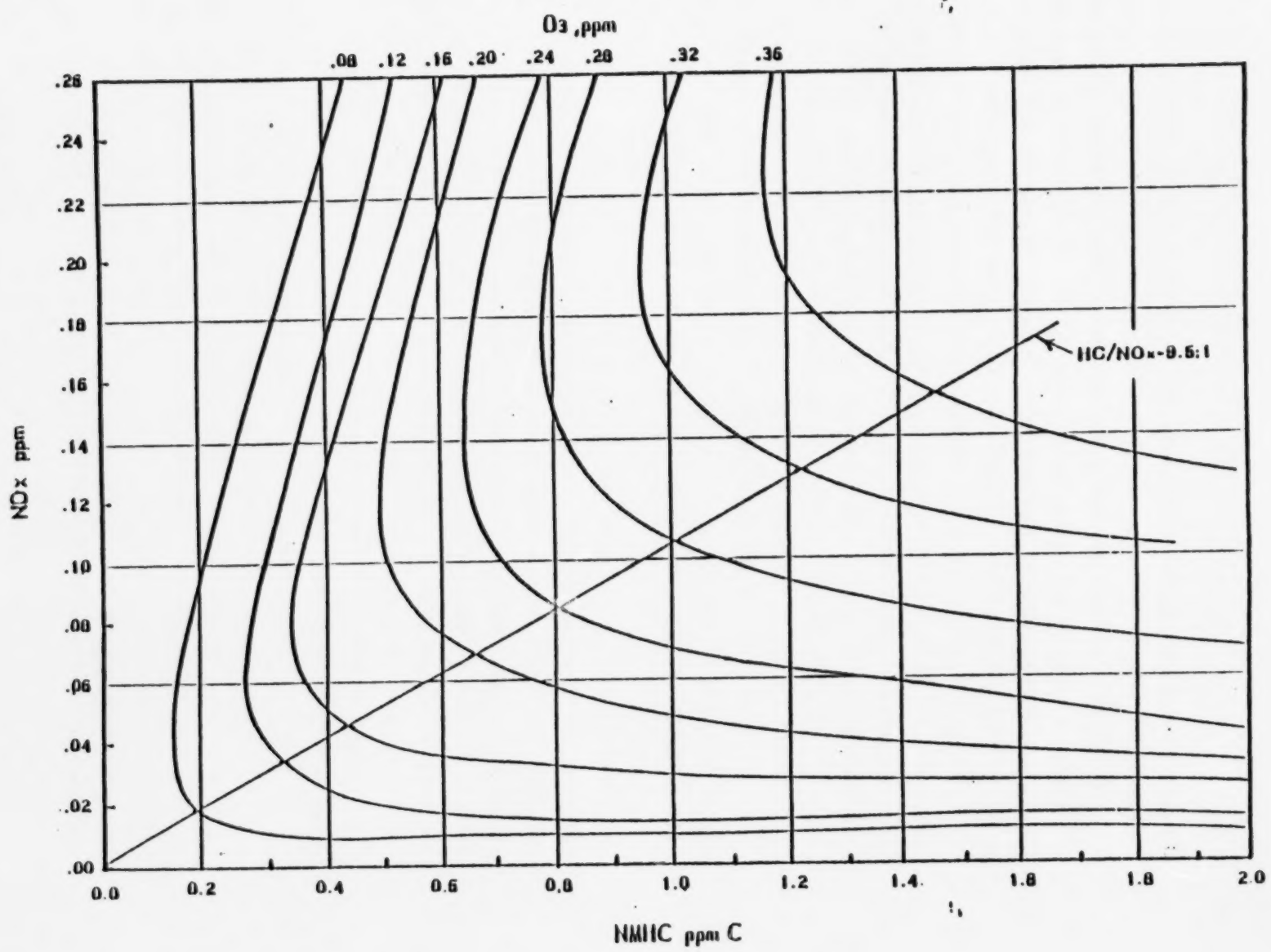
For several reasons, isopleth diagrams are most properly interpreted when used in a relative rather than an absolute sense. First, the absolute position of the isopleths depends upon a number of underlying assumptions concerning meteorological conditions and emission patterns.

Unless the meteorological conditions and emission patterns corresponding to those assumed in deriving the isopleths are similar to those occurring in the city of interest on days with high ozone concentrations, there is no reason to expect the absolute position of the isopleths to be correct. The relative positions of the isopleths, however, should be less sensitive to these differences. Sensitivity tests have indicated that predicted control requirements for emissions of volatile organic compounds (VOC) are not very sensitive to changing dilution rates, solar intensity, diurnal emission patterns and changes in reactivity when the isopleths are applied in a relative sense (Dodge, 1977). One advantage to beginning with the observed design value of O_3 as input to the EKMA is that this parameter inherently reflects the local prevailing meteorology on that day. In this respect, the standard isopleth approach is area-specific. It is crucial, of course, that the O_3 monitoring data have been collected at sites likely to record the maximum O_3 concentration in the region.

A second reason for applying the isopleths in a relative sense is that they reflect the behavior of one fixed mixture of automotive exhaust. Relative positions of the isopleths are less sensitive to the mix of ozone precursors assumed. Third, simulations in which the kinetics model was used to derive the standard EKMA isopleths did not include allowance for any injection of precursors after 8 a.m. LDT. A sensitivity test conducted with the model indicated that the maximum ozone concentration formed on the first day of the simulation is increased by post-8 a.m. precursor emissions (Dodge, 1977). However, this same sensitivity study indicated that estimated control requirements (using the isopleths in a relative manner) were generally insensitive to the post-8 a.m. emissions. It is important to point out that in the sensitivity studies, post-8 a.m. emissions were reduced in proportion to reductions in initial NMOC concentrations. Thus, in using the standard isopleths, proportional reductions in <u>all</u> emissions (both 6-8 a.m. <u>and</u> post-8 a.m.) must be assumed in order for the curves to be applied properly. No distinction

FIGURE 2-1

ISOPLETH CURVES FROM SMOG CHAMBER EXPERIMENT



can be made between 6-9 a.m. emissions and other emissions with the standard isopleths. Fourth, it should be kept in mind that the isopleths have been primarily validated against smog chamber data. Smog chambers represent a simplification of the urban atmosphere in that several contaminants which may have a potential impact on maximum O_3 may have been excluded from either the chamber or the model or both. Finally, a limitation in this method, as well as in linear rollback or any other empirical technique, is that there will always be some uncertainty about whether the maximum ozone concentration is measured. On any given day it is unlikely that the ozone monitor is at the precise location experiencing the maximum ozone concentration.

In the Los Angeles basin, standard EKMA tends to underestimate changes in ozone concentrations observed between the mid-1960's and the mid-1970's (Trijonis and Hunsaker, 1978). Studies are currently underway to compare both city-specific and standard versions of EKMA with more recent trends observed in the Los Angeles basin. Results of the 1978 Trijonis and Hunsaker study, as well as the more recent studies, indicate that the agreement between EKMA and Los Angeles trends is sensitive to the NMOC/NO_x ratio assumed to prevail in the mid-1960's.

Applying EKMA to a nationwide study by assuming the same NMOC/NO_x ratio in all AQCR's will produce some errors. Therefore, area specific ratios should be used whenever available. However, if the variance about the default 9.5:1 ratio is not large, then indicators like average percentage change in O_3 concentration and number of areas above the ambient standard should be meaningful for comparing control strategies.

2.1.5 Applications of EKMA to Ozone Strategies

For the rollback relationship to hold for ozone, there must be a single proportionality constant between VOC emissions and maximum ozone. Re-examining Figure 2-1 shows that this is not always the case. Even if it were assumed that the isopleths in Figure 2-1 are not absolutely

correct, the proportionality "constant" between NMOC and O_3 depends on (1) the prevailing level of NO_x and (2) the changes in NO_x accompanying hydrocarbon control strategies. For example, for O_3 = .28 ppm, according to Figure 2-1, the proportionality "constant" can be anything from 0.36 to 0.14. Proceeding from the O_3 = .28 isopleth down to the O_3 = .08 ppm isopleth at a constant NMOC/NO_x ratio of 9.5:1, one finds proportionality constants between NMOC and O_3 varying between .26 and .50.

As noted previously, control estimates are usually based on the scenario where transported ozone (from upwind areas) is diminished concurrently with implementation of local emission control programs. Ideally, this reduction would result in ozone transported to downwind cities being reduced to levels approaching natural background. Because transport and natural background affect maximum ozone via a similar mechanism (i.e., from aloft), to be consistent, natural background should be ignored if transport is ignored. For ozone design values in the range 0.15 to 0.16, the scenario in which transport is actually reduced, ignoring both transport and natural background results in calculated control requirements that are within ±5% of those in which reasonable estimates of both transport and natural background are considered. Hence, this approach may be considered adequate given the general uncertainty of the levels of present and future transport in many areas and the long time frame often considered in regulatory analyses.

An assumption in rollback is that the amount of VOC emission controls needed to attain the ozone standard is independent of the prevailing NMOC/NO_x ratio. However, smog chamber experiments suggest that the lower the ratio, the more effective the VOC reduction is in reducing the

TABLE 2-1

NATIONWIDE EMISSION ESTIMATES, 1977
(10^6 metric tons/year)

Source Category	NO_x	VOC	CO
Transportation	9.2	11.5	85.7
Highway Vehicles	6.7	9.9	77.2
Non-highway vehicles	2.5	1.6	8.5
Stationary fuel combustion	13.0	1.5	1.2
Electric utilities	7.1	0.1	0.3
Industrial	5.0	1.3	0.6
Residential, commercial, & institutional	0.9	0.1	0.3
Industrial processes	0.7	10.1	8.3
Chemicals	0.2	2.7	2.8
Petroleum refining	0.4	1.1	2.4
Metals	0	0.1	2.0
Mineral products	0.1	0.1	0
Oil & gas production & marketing	0	3.1	0
Industrial organic solvent use	0	2.7	0
Other processes	0	0.3	1.1
Solid waste	0.1	0.7	2.6
Miscellaneous	0.1	4.5	4.9
Forest wildfires & managed burning	0.1	0.7	4.3
Agricultural burning	0	0.1	0.5
Coal refuse burning	0	0	0
Structural fires	0	0	0.1
Miscellaneous organic solvent use	0	3.7	0
TOTAL	23.1	28.3	102.7

NOTE: A zero indicates emissions of less than 50,000 metric tons/year.

SOURCE: U.S. EPA, National Air Quality, Monitoring, and Emissions Trends Report, 1977 (EPA-450/2-78-052), Research Triangle Park, N.C., December, 1978.

maximum ozone formed. Thus, at very low NMOC/NO_x ratios, rollback may underestimate the effectiveness of VOC controls. Conversely, at high ratios, estimates obtained with rollback may be overly optimistic. With the prevailing ambient conditions which appear to be typical in many cities, the net effect of rollback assumptions is to estimate that less control is needed to attain the ozone standard than would be implied by the EKMA. Under the ambient conditions which apparently prevail in most cities, rollback is likely to differ most from predictions of kinetics models during the period in which initial control increments are exercised (i.e, when the NMOC/NO_x ratio is still relatively high). Thus, for example, if VOC emission reductions of 30 percent were implemented in a city experiencing moderate (9.5:1) NMOC/NO_x ratios, the corresponding improvement in maximum ozone concentrations may be considerably less than the 30 percent predicted with rollback. The risk in relying on rollback is that when the corresponding 30 percent reduction in ozone levels failed to materialize, questons may arise about whether controlling volatile organic compounds will ever be effective in reducing ambient ozone. Many of these questions would arise because a model which is not based directly on cause-effect relationships between ozone and its precursors is used. Therefore, use of rollback for estimating VOC reductions needed to attain the ozone standard is not recommended.

2.2 USE IN NATIONWIDE STUDIES

2.2.1 Carbon Monoxide

Concentrations of CO vary with time, season, and geographic location. These variations often follow predictable trends. In most cities, CO levels peak at 7 to 9 a.m., 4 to 7 p.m., and 10 p.m. to midnight. The first two peaks arise from automobile traffic coupled with meteorological conditions. The midnight peak can be primarily attributed to calm wind conditions which result in a reduced dispersion of CO emissions.

The highest CO levels tend to occur in the fall and winter. In the fall and winter seasons, the tendency toward colder ambient temperatures results in increased production of CO emissions from cars, in addition to CO emitted from other fuel burning sources. Also, the more stable atmospheric conditions and low wind speeds which occur during winter and fall result in decreased dispersion of CO emissions and contribute in substantial part to the occurrence of high ground level CO concentrations.

Carbon monoxide is commonly understood to be a mobile source problem with wide variations in concentrations within an urban area. As can be seen from Table 2-1, transportation sources emitted more than 80 percent of the anthropogenic CO emissions in the U.S. in 1977. Some cities show that mobile sources emit even a higher proportion of CO than 80 percent. For instance, the Denver SIP estimates that 93 percent of all CO emissions in 1978 were from motor vehicles in that region.

2.2.1.1 Applicability of Rollback

A recent study performed by SRI International (Shelar, Ludwig, and Shigeishi, 1979) for EPA's Office of Mobile Source Air Pollution Control studied CO source/receptor relationships in four urban areas. These areas were San Jose, Seattle, Phoenix, and Chicago. One of the purposes of this study was to identify the contribution of CO from local versus regional sources at sites where violations of the 8-hour CO standard are likely. The site chosen for study in San Jose was near a congested suburban intersection in a commercial area. The Seattle and Chicago sites were in heavily congested downtown areas. The site studied in Phoenix was downtown near government office buildings where parking lots filled and emptied during rush hours in the morning and evening. All of the sites were chosen because they were considered likely to have violations of the CO standard during the one week monitoring period. Both "local" and "background or regional" monitors were used at each site.

The results of the monitoring in these four cities illustrate two situations that can produce CO 8-hour standard violations. The first situation is where high traffic density and congested conditions produce excessively high CO emissions which cause high ambient levels. This situation is characterized by diurnal CO patterns which closely follow traffic level variations. The second situation is where an inversion forms to limit vertical mixing, and emissions during the time the inversion is in place build up to produce peak CO levels. CO violations during this time can be widespread in an urban area. However, there is no evidence to suggest that CO is transported from any distance during the inversion. If this is true, "local" emissions are responsible for high observed CO levels.

Because CO has been labeled as a "local" problem with variations in concentrations thought to be due to nearby traffic densities, little work has been done to characterize how CO concentrations can reach peak levels during periods when emissions are low. Therefore, there is considerable uncertainty in identifying which sources or types of sources are contributing to high nighttime levels of CO. For an application of rollback to be valid, it is important that the mix of sources contributing to the problem be accurately known. This issue is discussed further in Section 3.

In the CO Regulatory Analysis, the rollback equation was applied to estimate the number of counties that would have CO levels exceeding alternative ambient standards for CO in future years. Because of the different nature of mobile and stationary source CO emission problems, and the location of the existing monitoring network, it was concluded that recorded violations in CO nonattainment areas are due primarily to mobile sources and localized area sources. Therefore, only mobile source and other area source emissions were included in the emission inventories used in the rollback analysis. An analysis of large stationary

(point) sources was conducted and it indicated that stationary source emissions had negligible effects on existing urban monitor sites. Thus, the analysis assumed for existing problem areas that all reductions would come from controlling mobile and other area source emissions. The regulatory analysis assumes that 100 percent of all mobile source emissions in a county and 20 percent of all area source emissions affect concentrations at design value monitors. However, the mix of sources used in the CO regulatory analysis is not applicable for cases where high CO levels are measured during nighttime or early morning hours.

2.2.1.2 Comparison of Results Using Rollback and the Indirect Source Guidelines

In past uses of rollback for analyzing the impact of nationwide control programs on CO concentrations, it has been assumed that although CO is largely thought to be a "hot-spot" problem, that if the county or AQCR inventory used in the modeling accurately reflects the source contributions at the design value monitor, that rollback was appropriate for estimating future year CO concentrations. By comparing the technique for estimating the impact of changing localized emissions on nearby CO concentrations described in the Indirect Source Guidelines (U.S. EPA, 1978) with the rollback equation, the validity of this assumption can be tested. The difference in the procedure used to estimate future year CO concentrations using the Indirect Source Guidelines versus using rollback is only in the way the design value is chosen. The Indirect Source Guidelines use the HIWAY model along with traffic characteristics to estimate local CO contributions. (Background CO should be added to obtain a total concentration.) Rollback uses measured CO values in the urban area. Both methods use variations in emission rates due to changes in emission factors, vehicle miles traveled, and vehicle speed to estimate future year concentrations. Therefore, both methods of estimating future concentrations assume the basic relationship that emission changes result in proportional changes in air quality.

In any city where high CO concentrations are a localized phenomenon, rollback can be used instead of the Indirect Source Guidelines to estimate future year CO concentrations if (1) the monitor measuring the design value is in a location representative of the highest CO in the city, if (2) the emission sources affecting the monitor are well characterized, and if (3) the same meteorological conditions are assumed to prevail in the future. Then, the only difference between rollback and ISG predicted future CO concentrations is that monitored versus estimated concentrations, respectively, are used as design values.

2.2.2 Ozone

Ozone, a secondary pollutant, results from the reaction of non-methane organic compounds (NMOC) and oxides of nitrogen (NO_x). Ambient ozone concentrations occur as the result of two processes. One is a physical process involving dispersion and transport of the precursor emissions. The second is a chemical process involving reaction of the precursors under the stimulus of sunlight. Obviously, then, meteorological conditions are an important factor in determining ambient ozone levels. Atmospheric dilution and transport affect ambient pollutant levels and the geographic relationship between source areas and corresponding ozone problem areas. Solar radiation and ambient temperature affect the chemical processes.

Because meteorological conditions influence ozone formation to such a great extent, they tend to obscure both the absolute and relative effects of the emission-related factors to degrees that vary by geographic location and season. However, because nationwide analyses are the principal application for the modeling procedures described in this document, the average predicted changes in concentrations should not be unduly biased by yearly meteorological variations in a few cities.

In previous nationwide studies it has been informative to use both EKMA and rollback to produce separate estimates of expected ozone concentration

reductions in future years. However, EKMA is regarded as a more theoretically sound approach for estimating the effects of VOC reduction on ozone concentrations, and the use of rollback is no longer recommended.

2.2.3 Nitrogen Dioxide

The formation of NO_2 in the atmosphere is a highly complex process. NO, formed primarily as a result of fuel combustion, can be converted to NO_2 through oxidation with atmospheric oxygen, ozone or various organic compounds. Only about five percent of the NO_x in the combustion products is in the form of NO_2. Production of NO_2 by oxidation with atmospheric oxygen is immediate for NO concentrations greater than about 100 ppm and significant O_2 concentrations. Such high concentrations of NO only occur very near the point of exhaust, however. As the NO is diluted to concentrations below 100 ppm, the rate of conversion by oxygen decreases to a point where at 1 ppm, the direct reaction with O_2 becomes unimportant. For the most part, the NO to NO_2 conversion through this mechanism is limited to roughly ten percent of ambient NO_x concentrations.

Oxidizing agents such as ozone produce a rapid conversion of NO to NO_2. The degree of conversion, under certain conditions, is directly proportional to the level of ozone present. In the absence of photochemical activity, NO_2 formation due to O_3 is on a one-to-one basis. In the presence of ultra-violet light, an equilibrium set of reactions between NO_2 and ozone result. On days with high solar radiation, NO_2 levels are set by these competing reactions. The presence of organic pollutants (e.g., NMOC) may, in some cases, shift this equilibrium. In spite of these very complex chemical processes, some success in applying rollback in NO_x control strategies has been achieved, as will be shown in the following discussions.

Measured violations of the current annual average NAAQS for NO_2 are generally believed to be caused by area, especially mobile, sources.

Therefore, only area source emitters of NO_x are typically included in applications of the rollback model to NO_2 regulatory analyses. This approach is supported by recent studies on the relative impact of mobile and stationary sources on high NO_2 concentrations. One study analyzed NO_2, CO, and SO_2 data from the Welfare Island monitoring site in New York City (Iverach, 1978). It assumed that ambient SO_2 can be used as a surrogate for stationary source emissions and ambient CO can be used as a surrogate for mobile source emissions. Therefore, the concentrations of CO and SO_2 during periods of high NO_2 should show which source type predominates. The conclusion of the analysis was that on annual basis for the area around the Welfare Island, NY site, NO_x emitted from mobile and other area sources is more likely to result in high measured NO_2 than NO_x emitted from point sources.

Other studies also tend to suggest that mobile and area sources of NO_x are the primary contributors to the levels occuring at ambient monitoring sites. First, it has been shown (Chang, Norbeck, and Weinstock, 1980), using LA Basin data, that high one-hour NO_2 resulted mainly from vehicular sources. An examination of the NO_x/CO and SO_2/CO ratios shows that a significant impact of elevated NO_x sources on high NO_2 occurs rarely. In fact, a stationary (both ground level and elevated) source contribution of greater than 10 percent was rare at the LA Basin sites examined. The only exception to this would be a case where stationary sources with low stacks were near a monitor.

Chang, Norbeck, and Weinstock also concluded that rollback calculations that assume high hourly NO_2 concentrations are proportional to the total tonnage of NO_x emissions from all sources will greatly underestimate the improvement in NO_2 air quality to be expected from a reduction in vehicle NO_x emissions in the LA Basin. Therefore, source contribution factors must be used to discount the effect of emissions from stationary sources on observed NO_2 levels. See Section 3.5 for a further discussion of source contribution factors.

A recent study by SRI International (Martinez and Nitz, 1979) examined high (greater than 0.20 ppm) hourly NO_2 levels at 48 monitoring sites in California during 1975-77. Approximately 1800 site-days when NO_2 exceeded 0.20 ppm were reviewed. It was found that mobile source emitters predominated at all stations. Point-source effects linked to high hourly NO_2 were infrequent.

In addition, Martinez and Nitz found that high hourly NO_2 levels in Southern California coincide with increased emissions from stationary area sources of NO_x. The diurnal variations of the high NO_2 levels at the California monitors were associated with the traffic cycle. Therefore, some combination of mobile and stationary area sources contributes to peak NO_2 levels.

As noted above, these studies tend to support the contention that high measured NO_2 concentrations are attributable to mobile or other area source impacts and, thus point source emissions can be neglected. Therefore, although ambient concentrations of NO_2 are created by a mix of emissions from point and area sources, it is suggested that for regulatory analyses only area sources be modeled using rollback. This is a reasonable approach, particularly if, as appears true from the available evidence, most monitors in urban areas are sited to reflect contributions primarily from area sources of NO_x emissions.

REFERENCES FOR SECTION 2

Chang, T.Y., Norbeck, J.M., and Weinstock, B. February 1980. "NO_2 Air Quality -- Precursor Relationship: An Ambient Air Quality Evaluation in the Los Angeles Basin". J. Air Poll. Control Assoc. Volume 30, No. 2.

deNevers, N. and Morris, J.R. 1975. "Rollback Modeling: Basic and Modified," J. Air Poll. Control Assoc. Volume 25, No. 9.

Dodge, M.C. June 1977. Effect of Selected Parameters on Predictions of a Photochemical Model. EPA-600/3-77-048. U.S. EPA. Research Triangle Park, N.C.

Energy and Environmental Analysis, Inc. December 28, 1979a. Regulatory Impact Analysis for the National Ambient Air Quality Standards for Carbon Monoxide. Arlington, VA.

Iverach, D. August 1978. "A Technique for Estimating the Relative Impact of Mobile and Stationary Sources on NO_2 Concentrations". J. Air Poll. Control Assoc. Volume 28, No. 8.

Martinez, J.R. and Nitz, K.C. August 1979. Analysis of High NO_2 Concentrations in California, 1975-1977 EPA-450/4-79-034a. SRI International. Menlo Park, CA. (Prepared for U.S. EPA, RTP, NC).

Shelar, E., Ludwig, F.L., and Shigeishi, H. May 1979. Analysis of Pollutant and Meteorological Data Collected in the Vicinity of Carbon Monoxide "Hot Spots". Draft. SRI International, Menlo Park, CA. (Prepared for U.S. EPA, Ann Arbor, MI.)

Trijonis, J., Peng, T., McRae, G. and Lees, L. January 1976. "Emissions and Air Quality Trends in the South Coast Air Basin," EQL Memo No. 16 Environmental Quality Laboratory, California Institute of Technology, Pasadena, CA.

Trijonis, J. and Hunsaker, D. February 1978. Verification of the Isopleth Method for Relating Photochemical Oxidant to Precursors. EPA-600/3-78-019. Published by U.S. EPA, Research Triangle Park, NC.

U.S. Environmental Protection Agency. November 1977. Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors. EPA-450/2-77-021a. Research Triangle Park, NC.

U.S. EPA. September 1978. Guidelines for Air Quality Maintenance Planning and Analysis Volume 9 (Revised): Evaluating Indirect Sources. EPA-450/ 4-78-001 (OAQPS No. 1.2-028R). Research Triangle Park, NC.

U.S. EPA. February 1979. Cost and Economic Impact Assessment for Alternative Levels of the National Ambient Air Standards for Ozone. EPA-450/5-79-002. Research Triangle Park, NC.

3. SUGGESTED METHODOLOGIES FOR COMPILING MODELING DATA

This section discusses potential methodologies for compiling modeling data for use in a nationwide analysis of CO, O_3, or NO_2 concentrations. Procedures for estimating emission inventories, design values, growth rates, retirement rates, control effectiveness, source contributions, and transportation controls will be presented.

3.1 EMISSION INVENTORIES

The first step in compiling modeling data for use in applying rollback or EKMA is to collect an emission inventory for each region of interest. For each pollutant to be modeled, there are two key questions that must be answered before inventorying can begin. They are:

- What size area should be inventoried?
- Within this area, which source categories have a significant effect on monitored concentrations?

The first question can be answered by determining how large a source area typically affects design value concentrations of the pollutant being modeled. The design value and the emission inventory should be within a common boundary. Emission patterns and ambient air quality data are reviewed for each pollutant for a sample of urban areas to answer this question. To answer the second question, ambient data and modeling studies are examined separately for CO, O_3, and NO_2.

3.1.1 Ozone

In order to determine an appropriate source area for ozone, studies in a number of cities were reviewed. The first such study examined here was performed during the summer of 1977 in Tulsa, Oklahoma. (Eaton et al.,

1979) Ozone was monitored at 10 sites; NO/NO_x at eight sites; non-methane hydrocarbons at four sites; wind speed and direction at four sites; and solar radiation at one site. An airborne program measured ozone, NO/NO_x, temperature and other variables for seven days during the study period. This data base is useful in determining the spatial distribution of ozone and the relationship between major emission sources and observed maximum concentrations.

On three of the four days that the aircraft measured a distinct ozone plume, the maximum ozone concentration was measured approximately 48 km (30 mi) north of the center of Tulsa. (Aircraft monitoring flights were only made on days with consistent southerly winds). On the remaining day, the maximum ozone concentration was measured approximately 32 km (20 mi) downwind. It is interesting that the urban ozone plume did not experience a significant amount of spread in traveling the 64 km (40 mi) to the location of the aircraft final horizontal traverse. The average plume spread on all horizontal traverses was approximately 34 km (21 mi). The city of Tulsa is approximately 26 km (16 mi) wide in the east to west direction. Therefore, the ozone plume from Tulsa was only slightly wider than Tulsa and did not widen appreciably in traveling the 64 km downwind.

The morning ozone precursor concentrations at the downwind sites were generally very low compared to those measured in the city. Therefore, ozone synthesis from local sources at the downwind sites probably represents only a small contribution to the maximum ozone concentrations measured at those sites. This means that a large percentage of the ozone measured at those sites is from precursors which originated in the Tulsa metropolitan area.

In addition, during the study, three sites were considered to be simultaneously under urban influence on 39 days. The maximum ozone concentration in the network was measured at Vera (34 km downwind) on 49

percent of those days, at Ochelata (48 km downwind) on 32 percent of those days, and at Sperry (14 km downwind) on 8 percent of those days. This points out the widespread nature of high ozone levels, and the necessity of modeling a large enough area to include both the monitor with the highest O_3 levels and all sources affecting readings at that monitor.

Project Da Vinci II involved ambient monitoring aloft of ozone and precursors near and downwind of St. Louis (Decker et al., 1977). During this study, ozone concentrations measured aloft above the radiation inversion remained in the range 230 to 290 $\mu g/m^3$ from 1700 on June 8 until the flight was ended the next day. These measurements strongly suggest overnight transport of ozone aloft with minimum dilution and/or destruction. (i.e., <20 percent). In addition, the occurrence of high ozone concentrations (>250 $\mu g/m^3$) on the morning of June 9, 1976, in a rural area in southwest Indiana was attributed to long range transport of ozone from St. Louis. These measurements suggest that a large source area should be modeled for ozone analyses.

Ozone data collected during the St. Louis RAPS study are also useful for determining the appropriate source area for ozone. Table 3-1 shows monthly maximum ozone values for July, August, and September for 24 sites in and near St. Louis. They are classified by their distance and directional location with respect to the St. Louis Central Business District (CBD). The outermost sites are as much as 50 km from the CBD. A map of these sites is shown in Figure 3-1. The monthly maxima in Table 3-1 show no discernable pattern. At least one value greater than the 0.12 ppm hourly standard was measured during these three months at every site. Therefore, it is likely that a large source area contributes to the design value monitor in St. Louis. At the least, it can be concluded that a large area (AQCR) must be inventoried to ensure inclusion of all of the significant emissions affecting each site.

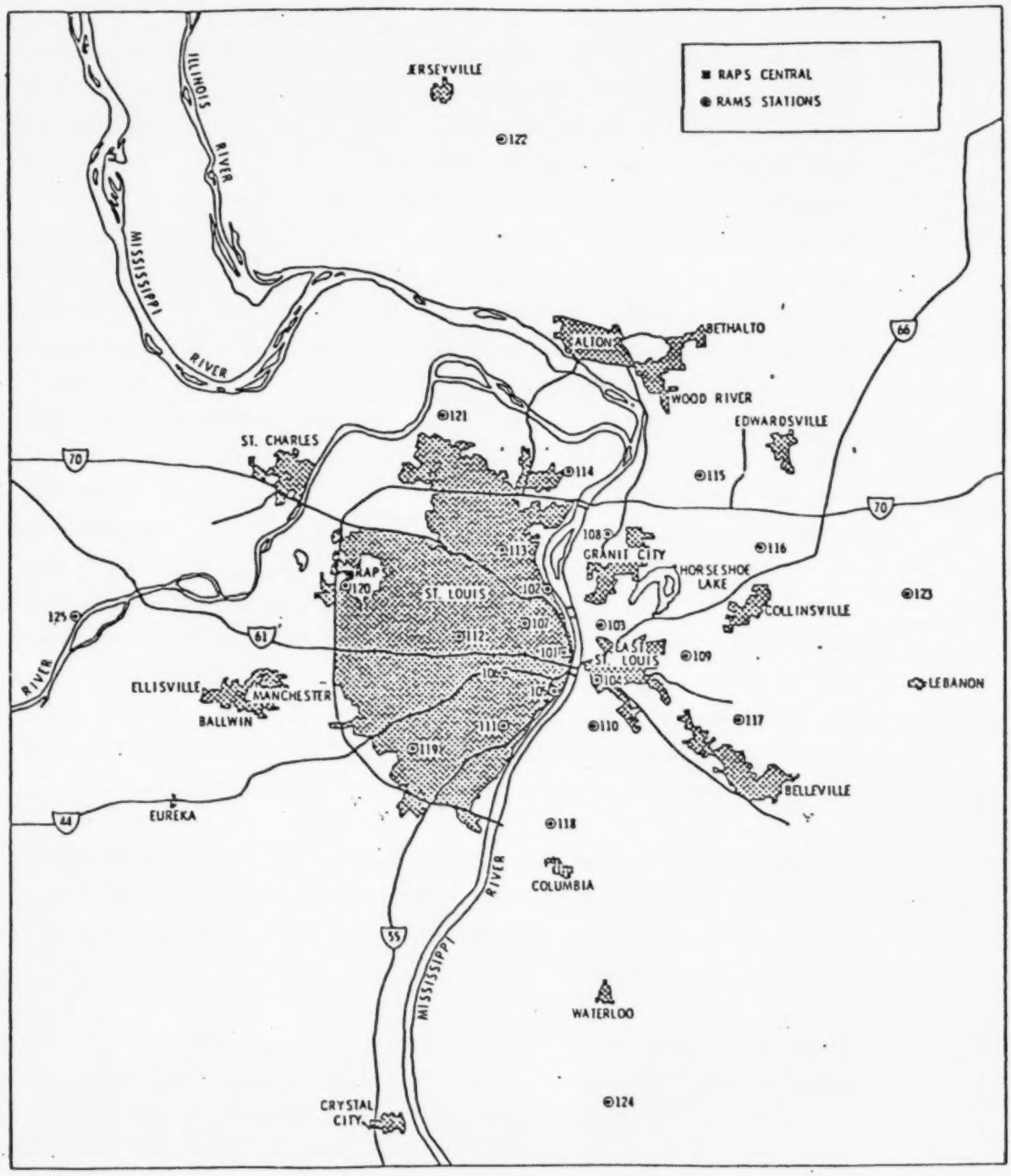
TABLE 3-1

MONTHLY MAXIMUM HOURLY OZONE FOR RAPS SITES IN ST. LOUIS (1976)
CONCENTRATIONS IN PPM

Site Clusters	Distance from Center City (km)	July	August	September
1. West of CBD				
125	50-60	0.145	0.168	0.106
2. Western Edge of CBD				
119	10-20	.126	.160	.107
120	10-20	.155	.176	.146
121	20-30	.126	.187	.109
3. Central Business District				
101	0	.151	.145	.092
102	≤0	.107	.149	.249
105	≤0	.122	.180	.098
106	≤0	.155	.169	.110
107	≤0	.154	.152	.090
111	≤0	.107	.134	.108
112	≤0	.154	.134	.188
113	10-20	.179	.158	.108
4. Downwind Edge of CBD				
103	≤0	.158	.202	.248
104	≤0	.112	.152	.087
110	≤0	.141	.146	.120
114	10-20	.223	.177	.132
118	10-20	.144	.143	.154
5. Downwind 10 km				
109	10-20	.159	.180	.120
115	20-30	.169	.192	.132
116	20-30	.167	.180	.124
117	10-20	.137	.166	.107
6. Outer Periphery				
122	50-60	.148	.190	.126
123	30-40	.141	.010	.109
124	40-50	.160	.111	.153

FIGURE 3-1

RAMS MONITORING SITES IN ST. LOUIS



Most, if not all, of the available evidence suggests that VOC inventories to be used in a nationwide rollback or EKMA modeling approach should be compiled on an AQCR basis. The only evidence presented here that suggests otherwise is the situation in Los Angeles, where it is suggested that a county inventory covers the source area affecting maximum ozone (Trijonis and Hunsaker, 1978). In order to estimate the error involved in using an AQCR inventory where a county inventory is appropriate, a sample of regions was used to compare the distribution of sources in a county versus an AQCR. Data for this comparison were taken from the National Emissions Data System (NEDS). Chicago, Washington, Los Angeles, Philadelphia, Baltimore, Detroit, Pittsburgh, and Houston were the cities used in the comparison. The results of this comparison are shown in Table 3-2. The only area with a significant difference between the distribution of sources is Washington, DC. The percentage of mobile source emissions in the District of Columbia is much lower than it is in the remainder of the AQCR. Because of the way NEDS calculates mobile source emissions, the miles traveled in DC by vehicles registered and fueled in the neighboring States of Maryland and Virginia are probably not included in the DC totals. Therefore, it is likely that in actuality, the distributions of emissions in the District of Columbia alone and in the entire AQCR are approximately equal.

Because the source distributions are roughly the same in counties and in the AQCR's that encompass those counties, if AQCR inventories are used in all areas, when in some cases a county inventory is appropriate, the resulting errors will be minor.

It is recommended that VOC inventories for use in nationwide analyses be compiled using the source categories listed in Table 3-3. These categories are essentially the same as those recommended by EPA for use in preparing VOC emission inventories (U.S. EPA, 1977). Therefore, they correspond closely to the inventories included in the SIP's. National

TABLE 3-2

DISTRIBUTION OF VOC SOURCES FOR COUNTY VERSUS AQCR INVENTORIES FROM NEDS
PERCENTAGE OF ANNUAL EMISSIONS IN EACH SOURCE CATEGORY

Source Categories	AQCR 216 Houston	Harris County	AQCR 197 SW Penn	Allegheny County	AQCR 123 Detroit	Wayne County	AQCR 115 Baltimore	Baltimore County
1. Petroleum Refineries	.07	.03	0	0	.01	.02	.01	.03
2. Storage, Transportation and Marketing of Petroleum Products	.18	.24	.05	.04	.05	.05	.04	.04
3. Industrial Processes	.31	.19	.09	.12	.02	.03	.04	0
4. Organic Solvent Evaporation	.19	.23	.41	.37	.54	.50	.45	.50
5. Stationary Combustion Sources	.01	.02	.01	.01	.02	.02	.02	.01
6. Mobile Sources	.24	.29	.44	.47	.36	.38	.44	.42

Source Categories	AQCR 047 National Capital	D.C.	AQCR 067 Chicago	Cook County	AQCR 045 Philadelphia	Philadelphia County	AQCR 024 Los Angeles	Los Angeles County
1. Petroleum Refineries	0	0	.01	0	.03	.01	.05	.06
2. Storage, Transportation and Marketing of Petroleum Products	.05	0	.10	.04	.19	.04	.06	.07
3. Industrial Processes	0	0	.03	.01	.04	.01	0	0
4. Organic Solvent Evaporation	.37	.64	.48	.54	.37	.42	.45	.49
5. Stationary Combustion Sources	.01	.01	.02	.01	.01	0	.04	.04
6. Mobile Sources	.57	.35	.37	.40	.36	.51	.39	.34

TABLE 3-3

VOLATILE ORGANIC COMPOUND EMISSION INVENTORY
SOURCE CATEGORIES

Stationary Sources

1. Petroleum Refineries
2. Storage, Transportation and Marketing of Petroleum Products
3. Industrial Processes
4. Industrial Surface Coating
5. Other Solvent Use
6. Other Miscellaneous Sources

Mobile Sources

7. Light-Duty Gasoline Vehicles
8. Light-Duty Diesel Vehicles
9. Light-Duty Trucks
10. Heavy-Duty Gasoline Trucks
11. Heavy-Duty Diesel Trucks
12. Other Transportation Sources

Emissions Data System (NEDS) data can also be easily structured into these source categories. Light-duty diesel numbers are not readily available at this time from NEDS, however.

3.1.2 Carbon Monoxide

CO concentration patterns across a city relate primarily to nearby traffic levels and meteorological conditions. The most important meteorological variables are wind speed, atmospheric stability, and mixing height. CO concentrations usually vary greatly within an urban area, so it is important to characterize only those emissions near the design value monitor. However, two meteorological conditions, occurring simultaneously or separately, can occur to produce widespread high CO levels. One is thermal circulation, such as sea-land breezes, lake-land breezes, drainage winds, or mountain-valley winds, that is caused by differential heating of topographic features. These winds generally flow in one direction during the day, then in the opposite direction at night. As a result, an urban area can experience "blowback" of CO emissions emitted during the day resulting in higher CO concentrations at night. The second meteorological condition that can lead to widespread high CO is inhibited vertical mixing caused by high atmospheric stability or presence of a shallow mixed layer. An important example of limited vertical mixing occurs as the result of a "surface" or "radiative" inversion. Such conditions usually occur at night, with light winds and clear skies. The surface inversion usually persists for hours and, because it typifies stable atmospheric conditions, it can lead to high and relatively widespread CO concentrations.

Presence of a shallow mixed layer may often occur as the result of a subsidence inversion, caused by the adiabatic warming of a descending atmospheric layer. The subsidence inversion usually persists on the order of days and tends to contribute to high urban background CO concentrations.

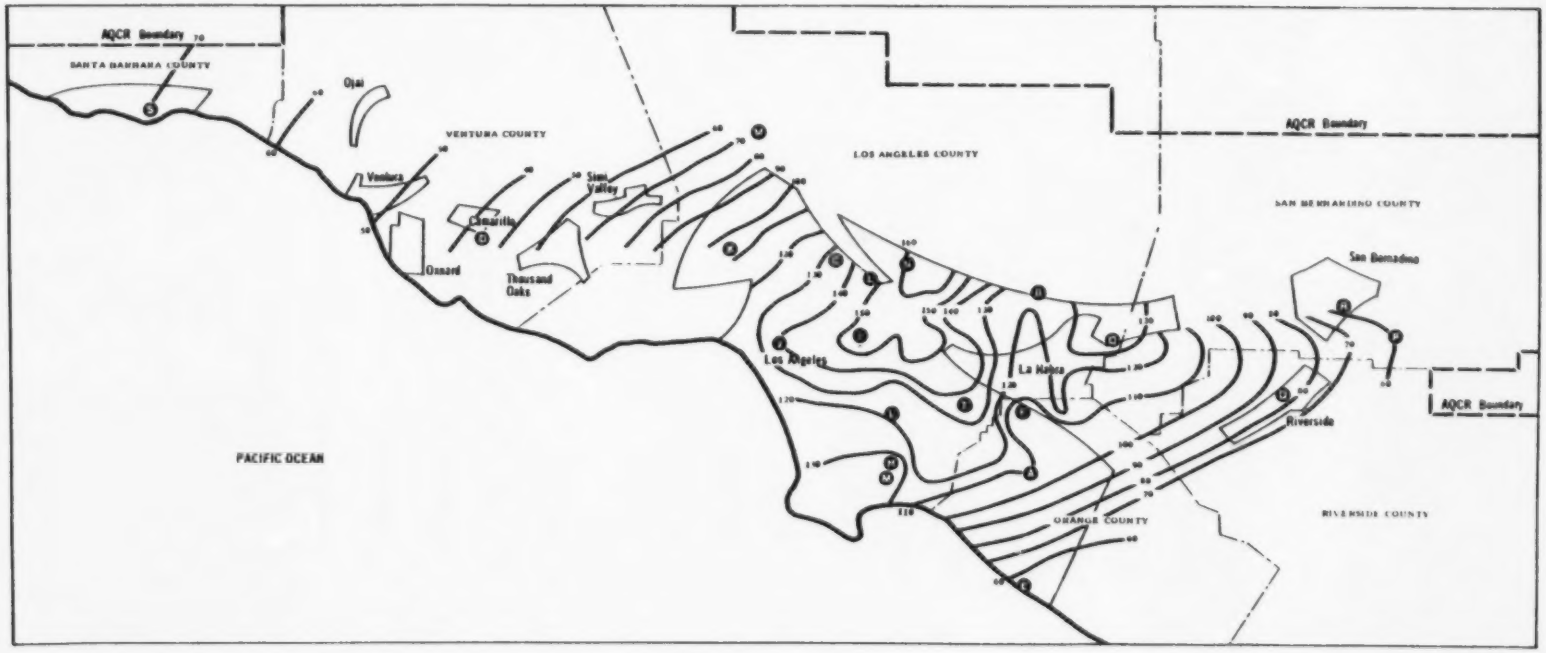
Because CO problems seem to be predominantly related to microscale emission levels, and occasionally more widespread emissions (in the presence of adverse meteorological conditions), the recommended inventory area is a county. While in many cases, nonattainment areas for CO are smaller than a county (sometimes they include only a few blocks in a downtown area) for practical purposes a county inventory is the most reasonable approach for a nationwide study. This is true because the NEDS summaries are available only down to the county level.

Table 3-4 lists the source categories suggested for compiling county emission inventories for use in a nationwide analysis. These categories are recommended based on the assumption that stationary sources of CO do not significantly affect concentrations measured at design value monitors, and the source categories typically used in NEDS are sufficient (see Section 3.5 for a more complete discussion of source contributions).

3.1.3 Nitrogen Dioxide

Observed concentrations of NO_2 result primarily from chemical reactions in the ambient air involving NO and other pollutants. The principal mechanisms leading to high NO_2 levels are photochemical synthesis and the reaction of NO with ozone (titration). Photochemical synthesis occurs when NO and NMOC react in the presence of sunlight to form NO_2. Site locations which primarily experience high NO_2 concentrations due to photochemical synthesis are usually within 1-4 hours travel time of where heavy NO_x and VOC emissions occur. The titration reaction of NO with ozone to form NO_2 occurs very rapidly in the atmosphere, much faster than the photochemically driven synthesis.

FIGURE 3–2
1977 NO_2 CONCENTRATIONS IN THE LOS ANGELES AIR QUALITY CONTROL REGION



MONITORING SITE AND READINGS

A - Anaheim 109	F - La Habra 104[1]	K - Los Angeles Cty. 105	P - Redlands 60
B - Azusa 121	G - Lennox 122	L - Lynwood 120	Q - Rubidoux 85[2]
C - Burbank 134	H - Long Beach 131	M - Newhall 66	R - San Bernardino 56
D - Camarillo 43	I - Los Angeles 156	N - Pasadena 163	S - Santa Barbara 70[2]
E - Costa Mesa 54[2]	J - Los Angeles 148	O - Pomona 134	T - Whittier 136

1977 ARITHMETIC MEAN ($\mu g/m^3$)

1 Measured by Saltzman Colorimetric Method

2 Mean derived from less than 75% of total possible observations

0 20

MILES

N

TABLE 3-4

CARBON MONOXIDE EMISSION
INVENTORY SOURCE CATEGORIES

Mobile Sources

1. Light-Duty Gasoline Vehicles
2. Light-Duty Diesel Vehicles
3. Light-Duty Trucks
4. Heavy-Duty Gasoline Trucks
5. Heavy Duty Diesel Trucks
6. Other
   - Off-Highway
   - Rail
   - Aircraft
   - Vessels

Stationary Sources

7. External Combustion
   - Residential
   - Industrial
   - Commercial-Institutional
8. Solid Waste Disposal
9. Miscellaneous

Therefore, a monitor with high NO_2 readings produced by a reaction with ozone is most likely near significant NO sources.

Because the highest annual average NO_2 concentrations will be measured at less than four hours travel time, and oftentimes immediately downwind, of significant NO_x sources, it seems appropriate to compile NO_x inventories for nationwide studies on a county basis. This conclusion can be judged further by examining spatial variation patterns of ambient NO_2 data.

Few areas have enough NO_2 monitors to allow spatial variation patterns to be determined. The Los Angeles Basin and the St. Louis area do have sufficient data; Los Angeles through regular monitoring and St. Louis from the RAPS study. Figure 3-2 shows isopleths of annual average NO_2 in the Los Angeles Basin from 1977 data. Based on the Los Angeles data, for an analysis of annual mean NO_2, it is probably appropriate to use a county inventory.

During 1976, 18 individual stations monitored hourly NO_2 concentrations in St. Louis as part of the RAPS study. The site locations are shown in Figure 3-1. Site 101 is in the city center. If the other sites are grouped with respect to their distance from site 101, conclusions can be made about the spatial variation in NO_2 concentrations in the vicinity of St. Louis.

Site Distances from the City Center (km)	Number of Sites	Annual Average NO_2 (ppm)
0	1	.028
0–4	3	.027
4–10	5	.027
10–20	7	.015
20–30	2	.012

The annual averages in the above table are averages of the 1976 annual means at all of the sites in each group. While the annual averages within 10 km of the city center are relatively constant at .027-.028 ppm, there is a considerable drop in the annual average at sites more than 10 km from site 101. Therefore, it seems reasonable to assume that a county rather than an AQCR-wide emission inventory is appropriate for characterizing the sources contributing to the design value concentrations in St. Louis. This is consistent with the findings in Los Angeles.

NO_x emission inventory source categories recommended for use in nationwide studies are shown in Table 3-5. Point sources are aggregated into one category because it was found that point sources do not significantly impact NO_2 concentrations at the present set of continuous NO_2 monitors. They can be used in emission projections, however. Source contributions are discussed further in Section 3.5.

3.2 DESIGN VALUES

The design value is defined as the concentration that must be reduced to the level of the standard for an area to be in attainment. In using ambient monitoring data in national strategy assessments, design values are usually chosen to correspond to the form of the standard for each pollutant. In addition, design values can be chosen from a time period consistent with the emission inventory. Therefore, recommended techniques for determining design values are presented separately for CO, O_3, and NO_2. The EPA Storage and Retrieval of Aerometric Data (SAROAD) System is the source of monitoring data typically used to determine design values for use in nationwide studies. SAROAD is simply a compilation of ambient air quality data from air monitoring operations of State, local, and Federal networks.

TABLE 3-5

OXIDES OF NITROGEN EMISSION
INVENTORY SOURCE CATEGORIES

Mobile Sources

1. Light-Duty Gasoline Vehicles
2. Light-Duty Diesel Vehicles
3. Light-Duty Gasoline Trucks
4. Heavy-Duty Gasoline Trucks
5. Heavy-Duty Diesel Trucks
6. Other Mobile Sources
   - Off-Highway
   - Aircraft
   - Vessels
   - Locomotives (Rail)

Fuel Combustion (Area Sources)

7. Residential Oil/Gas
8. Comm/Inst. Coal
9. Comm/Inst. Oil/Gas
10. Industrial Coal
11. Industrial Oil/Gas
12. Other

TABLE 3-5 (Continued)

Solid Waste

13. S.W. Disposal

Point Sources

14. Point Sources

3.2.1 Carbon Monoxide

There are currently two NAAQS for carbon monoxide; an eight-hour standard of nine ppm and a one-hour standard of 35 ppm. As a result of the review and revision of the health criteria, EPA has recently proposed to lower the one-hour standard to 25 ppm (45 FR 55066). For the most part, the eight-hour standard is more stringent; therefore, all of the design values used in this study are for an eight-hour averaging time.

Under the present form of the standard, design values are determined by choosing the second highest monitor reading (non-overlapping) in any year. Thus, the highest second high in the three year period encompassing the emission inventory base year should be chosen as the design value.

While this technique for choosing a design value is acceptable given the current deterministic form of the standard, a change to a statistical standard has been proposed. A daily interpretation of exceedances of the CO NAAQS has been proposed which is consistent with the interpretation of exceedances for the ozone NAAQS.

3.2.2 Ozone

The ozone NAAQS contains the phrase "expected number of days per calendar year." This differs from the previous NAAQS for photochemical oxidants which specifies a concentration "not to be exceeded more than once per year." Although the new standard form appears to be complicated, the basic principle is relatively straightforward. In general, the average number of days per year above the level of the standard must be less than or equal to one. The simplest method for determining compliance with the standard is to record the number of exceedances at each site each year and then average this number over the past three years to determine if it is less than or equal to one. Adjustments can be made for incomplete monitoring data and year to year variations in emissions and meteorology. (U.S. EPA, 1979a).

Because the choice of a design value is primarily influenced by the few highest values in a data set, it is possible to construct a simple table look-up procedure to determine a design value (U.S. EPA, 1979a). To use this tabular approach, it is only necessary to know the total number of daily values and a few of the highest values. For example, if there are 1,017 daily values, then the ranks of the lower and upper bounds obtained from Table 3-6 are 3 and 2. This means that an appropriate design value would be between the third-highest and second-highest observed values. In using this table, the upper bound should be used as the design value.

For data sets that are 75 percent complete, but still have less than 365 days of data, the maximum observed concentration may be used as a tentative design value as long as the data set was 75 percent complete during the peak times of the year.

For a complete discussion of this table look-up procedure and other alternative methods for estimating ozone design values, refer to the Guideline For the Interpretation Of Ozone Air Quality Standards (U.S. EPA, 1979a).

3.2.3 Nitrogen Dioxide

Annual average NO_2 design values can be simply determined by choosing the highest annual average from the past three years. However, care should be taken to ensure that only valid annual averages are considered in choosing a design value. SAROAD uses the criterion for calculating annual means from continuous observations with sampling intervals of less than 24 hours that data must reflect a minimum of 75 percent of the total number of possible observations for the applicable year. Criteria for noncontinuous observations with sampling intervals of 24 hours or greater are as follows:

TABLE 3-6

TABULAR ESTIMATION OF DESIGN VALUE

Number of Daily Values	Rank of Upper Bound	Rank of Lower Bound	Data Point Used for Design Value
365 to 729	1	2	highest value
730 to 1094	2	3	second highest
1095 to 1459	3	4	third highest
1460 to 1824	4	5	fourth highest
1825 to 2189	5	6	fifth highest

SOURCE: U.S. EPA. January 1979. Guideline for the Interpretation of Ozone Air Quality Standards. EPA-450/4-79-003. OAQPS No. 1.2-108. Research Triangle Park, NC.

- Data representing quarterly periods must reflect a minimum of five observations for the applicable quarter. If there are no measurements in one of the three months of the quarter, each remaining month in that quarter must have no less than two observations reported.

- Data representing annual periods must reflect four quarters of observation that have satisfied the quarterly criteria.

3.3 GROWTH AND RETIREMENT RATES

3.3.1 Stationary Sources

Changes in stationary source activity levels are accounted for in the rollback model by a combination of growth and retirement rates. This is done because regulations affecting new sources differ from those affecting existing sources. Therefore, different control assumptions are identified for each. Growth rates and controls are applied to estimate new source emissions. Retirement rates are applied to estimate how emissions from existing sources will decrease.

The most recent industry-by-industry projections of growth applicable to an air pollution analysis are those performed by the Bureau of Economic Analysis (BEA, 1977). They are shown in Table 3-7. These growth rates were calculated based on earnings and, therefore, are assumed to represent net growth for an industry. In other words, retirement of existing sources is taken into account. Retirement rates for existing sources are shown in Table 3-8. These estimates of plant retirement rates were developed for EEA by Data Resources, Inc. (U.S. DOE, 1979) in support of EEA's ISTUM model development.

The equation which should be used to incorporate the data in Tables 3-7 and 3-8 is as follows:

TABLE 3-7

STANDARD INDUSTRIAL CLASSIFICATION (SIC) ANNUAL GROWTH RATES*

Industry	SIC	Average Annual Growth (1977-2000)
Agriculture	1-7	0.6
Forestry and Fisheries	8-9	1.7
Metal Mining	10	1.3
Coal Mining	11-12	3.1
Oil and Gas Extraction	13	2.2
Mining and Quarrying	14	1.5
Contract Construction	15-17	3.6
Food and Kindred Products	20	1.2
Textile Mill Products	22	2.4
Apparel and Other Textiles	23	2.0
Lumber and Furniture	24-25	2.3
Paper and Allied Products	26	2.7
Printing and Publishing	27	2.3
Chemicals and Allied Products	28	3.1
Petroleum Refining	29	1.9
Primary Metal Industries	33	2.4
Fabricated Metal Products	34	2.5
Machinery, Except Electrical	35	2.6
Electrical Machinery	36	2.9
Transportation Equipment	37	1.5
Miscellaneous Manufacturing Industries	39	3.3
Railroad Transportation	40	0.2
Motor Freight Transportation	42	3.2
Transportation Services	47	2.9
Communication	48	4.9
Electric, Gas and Sanitary Services	49	3.5
	Population Growth Rate	0.8

SOURCE: Bureau of Economic Analysis, 1977.

* Based on projected earnings by industry, calculated in 1967 dollars.

TABLE 3-8

INDUSTRIAL RETIREMENT RATES

Industry	SIC	Average Annual Retirement Rates
Agricultural Production	01	4.26
Agricultural Services	07	4.26
Forestry	08	4.26
Fishing, Hunting, and Trapping	09	4.26
Metal Mining	10	4.26
Anthracite Mining	11	4.26
Bituminious Coal and Lignite Mining	12	4.26
Oil and Gas Extraction	13	4.26
Mining and Quarrying	14	4.26
Building Construction	15	4.26
Construction Other than Buildings	16	4.26
Construction - Special Trade	17	4.26
Food and Kindred Products	20	4.56
Tobacco	21	3.35
Textile Mill Products	22	3.20
Apparel	23	3.18
Lumber and Wood Products	24	6.37
Furniture and Fixtures	25	3.68
Paper and Allied Products	26	4.13
Printing and Publishing	27	4.92
Chemicals and Allied Products	28	5.07
Petroleum Refining	29	4.48
Rubber and Miscellaneous Plastics	30	2.97
Leather and Leather Products	31	4.09
Stone, Clay, Glass and Concrete	32	4.93
Primary Metal Industries	33	4.97
Fabricated Metal Products	34	3.23
Machinery, Except Electrical	35	4.10
Electrical Machinery	36	4.61
Transportation Equipment	37	4.09
Miscellaneous Instruments	38	4.83
Miscellaneous Manufacturing Industries	39	4.41
Railroad Transportation	40	4.26
Interurban Transit	41	4.26
Motor Freight Transportation	42	4.26
U.S. Postal Service	43	4.26
Water Transportation	44	4.26
Air Transportation	45	4.26
Pipe Lines, Except Natural Gas	46	4.26
Transportation Services	47	4.26
Communication	48	4.26
Electric, Gas and Sanitary Services	49	4.26
General Government, Except Finance	91	4.26
Justice, Public Order, and Safety	92	4.26
Public Finance and Taxation	93	4.26

SOURCE: U.S. Department of Energy, 1979.

$$Q_n = Q_o \{[(1 + G_i)^t - 1] F_n + (1 - R_i)^t F_e + [1 - (1 - R_i)^t] F_n\} \qquad (3\text{-}1)$$

where:

Q_n = emissions in projection year

Q_o = emissions in base year

R_i = retirement rate

F_e = emission factor ratio for existing sources

G_i = growth rate

F_n = emission factor ratio for new sources

The first term in the equation represents new source growth and controls, the second term accounts for retirement and controls for existing sources, and the third term accounts for replacement source controls. It should be noted that the G_i term in equation (3-1) represents net growth. If a total growth rate (G_i') is used, the first term in equation (3-1) should be changed to $[(1 + G_i' - R_i)^t - 1] F_n$. (Estimates for F_e and F_n are discussed in Section 3.4.)

In order to facilitate use of the growth and retirement rates in Tables 3-7 and 3-8 in a nationwide analysis, Tables 3-9 and 3-10 are included. They present the data in Tables 3-7 and 3-8 for 15 different stationary source category groupings commonly used in nationwide analyses. Annual percentage ranges in growth and retirement along with the applicable SIC category are shown in the tables.

3.3.2 Mobile Sources

One of the most difficult and important variables to project for future years is growth in vehicle miles traveled (VMT) which is used as a surrogate for mobile source emissions growth. Growth in VMT is difficult to predict for two reasons. One is the uncertainty in how changes in fuel prices will affect demand for gasoline and travel. The second is

TABLE 3-9

STATIONARY SOURCE ACTIVITY LEVEL GROWTH

	Source Categories	1975-1995 Annual Percentage Change	Assumed SIC
1.	External fuel combustion	3.5	49
2.	Internal fuel combustion	3.5	49
3.	Chemical manufacturing	3.1	28
4.	Food/agriculture industry	0.6	20
5.	Primary metal products	2.4	33
6.	Mineral products	1.3	10
7.	Petroleum industry	1.9	29
8.	Wood products	2.3	24
9.	Industrial solvent evaporation	3.3	39
10.	Other industrial processes	3.3	39
11.	Solid waste disposal	0	-
12.	Petroleum storage & transport	1.9	29
13.	Gasoline service stations	1.9	29
14.	Area source solvent evaporation	0.8	population
15.	Miscellaneous	0	-

SOURCE: BEA, 1977.

TABLE 3-10

STATIONARY SOURCE RETIREMENT RATES

		Annual Percentage Change	Assumed SIC
1.	External fuel combustion	4.3%	49
2.	Internal fuel combustion	4.2	49
3.	Chemical manufacturing	5.1	28
4.	Food/agriculture industry	4.6	20
5.	Primary metal products	5.0	33
6.	Mineral products	4.9	10
7.	Petroleum industry	4.5	29
8.	Wood products	6.4	24
9.	Industrial solvent evaporation	4.4	39
10.	Other industrial processes	4.4	39
11.	Solid waste disposal	0	-
12.	Petroleum storage and transport	4.5	29
13.	Gasoline service stations	4.5	29
14.	Area source solvent evapoation	0	-
15.	Miscellaneous	0	-

SOURCE: U.S. DOE, 1979.

identifying how VMT will change in the areas that specifically affect high pollutant levels. For instance, growth in VMT in central business districts may vary from that in outlying areas. VMT is an important variable to estimate accurately because the rollback or EKMA predictions are sensitive to the value assumed, especially if projections are made more than 10 years into the future.

On a nationwide basis, VMT has historically grown at a rate of slightly over four percent per year (Congress, 1979). Immediately prior to the 1973-1974 oil embargo, annual growth reached nearly five percent. After a rapid drop during the embargo, VMT gradually increased again to a four percent annual rate. However, recent events suggest that fuel prices will continue to rise, and VMT may not increase as rapidly as historical trends indicate. Gasoline consumption fell by five percent in 1979 and is down eight to nine percent so far this year (1980). (With recent fuel economy gains, changes in gasoline consumption do not track directly into VMT changes). Until the elasticity of gasoline demand with respect to price can be quantified, it is only speculation how VMT will change in future years.

The California Transportation Department determined that weekend traffic on State highways declined by 11 percent last December (1979) from a year earlier. However, weekday traffic increased by four percent. It is important to make this differentiation when performing an air pollution analysis, because the traffic affecting the periods of highest concentration are of interest. Assuming that most high concentrations are observed on a week day, growth in travel during that period should be used.

Although one response to rising gasoline prices is reducing the number of trips, work trips are not likely to be reduced as much as trips for other purposes. These are the trips that contribute most to high pollutant levels. Therefore, in estimating future VMT growth rates, it is important not to use total VMT changes when weekday travel is of interest.

The second major issue regarding VMT growth estimates is that only the VMT specifically affecting the design value concentrations should be considered in growth projections. This means that SMSA growth rates are not always applicable. If the nonattainment area is the central business district, then expected growth in VMT in that area alone should be included in the projections. In addition, if a specific time period of the day is of interest, e.g., 6-9 a.m., then VMT changes for that period should be accounted for as much as possible.

Despite the fact that in most analyses the same growth rate is used for all mobile source categories, it is appropriate to use a separate growth rate for each vehicle type if possible. Therefore, the nationwide average growth rates presented in Table 3-11 are specific to each vehicle type. The 1977 market share for diesels is negligible when compared with 1990. Therefore, total VMT estimates are shown for both years.

In cases where nationwide average growth rates do not apply and it is necessary to estimate how VMT growth on urban roads (especially within the CBD) is likely to change in future years, it is useful to consider how roadways are designed. Rather than build a road to handle the maximum volume likely to travel on it during a year, traffic engineers either measure or estimate the hourly distribution of traffic volume during a year, pick an hourly traffic volume along that distribution, and build the roadway with the chosen capacity. This is done because it is uneconomical to provide for the extreme hourly volumes of traffic that may occur but a few times during a year. Based on the relationship between the peak hourly flows and the annual average daily traffic, it has been determined that the ratio of benefit to expenditure is near its maximum at the thirtieth highest hourly traffic volume (Wohl and Martin,

TABLE 3-11

MOBILE SOURCE GROWTH RATES*

	Annual Percentage Change	1977 VMT_9 ($\times 10^9$)	1990 VMT_9 ($\times 10^9$)
A. Highway Vehicles			
1. Gasoline			
a. Light-Duty Vehicles	0.5%		
b. Light-Duty Trucks I	2.3		
c. Light-Duty Trucks II	6.2		
d. Heavy-Duty Trucks	-2.0		
e. Motorcycles	2.5		
2. Diesel			
a. Light-Duty Vehicles	-	1.23	201.79
b. Light-Duty Trucks I	-	0	32.19
c. Light-Duty Trucks II	-	0	33.65
d. Heavy-Duty Trucks	5.0		
B. Off-Highway Vehicles			
1. Gasoline	2.3		
2. Diesel	2.3		
C. Locomotives	0.2		
D. Aircraft	2.7		
E. Vessels	2.7		

* Light-duty vehicle and light-duty truck growth are estimated from data presented in McNutt, Dulla, and Lax, 1979. Heavy-duty truck growth rates are taken from U.S. EPA, 1979b. Growth for motorcycles is assumed to be 2.5%, which is FHWA's latest estimate of expected growth in VMT for the vehicle fleet as a whole. For off-highway vehicles, growth rates are estimated from projections of growth in earnings by industry (BEA, 1977).

1967). Hence, for most cases, the thirtieth highest hourly volume for the year is generally a reliable criterion of the needed capacity for which it is most practical to design.

This design criterion, if commonly used, has important implications for analyzing future VMT growth. If peak hour traffic is of interest, and roadway capacity is typically reached an average of 30 times per year, then even if VMT grows during off-peak periods, mobile source contributions to peak pollutant levels are unlikely to change. However, this conclusion is dependent on the averaging time of the standard being examined.

A question that has been raised a number of times with respect to nationwide studies is whether area specific growth rates should be used for mobile sources. In order to test the sensitivity of rollback results to the use of area specific growth rates, a test case was run using the data from the CO regulatory analysis. The results are shown in the table below:

Average Percentage Changes in CO Concentrations
(1976 Base Year)

Growth Scenarios	Projection Years				
	1982	1985	1987	1990	1999
No Growth	-28	-46	-54	-61	-65
1% Growth	-25	-41	-49	-56	-58
3% Growth	-16	-32	-39	-45	-39
Area Specific Growth	-17	-33	-40	-46	-40

The above table shows that rollback predictions are sensitive to the assumed growth rate, but that area specific growth rates are roughly

equivalent to using a three percent VMT growth assumption for the whole country. The indicators of "number of cities above the standard" and "the total number of expected violations" are also essentially equivalent for the three percent and the area specific growth assumptions. The area specific growth rates are based on DOT-FHWA projections from 1975-1990. These projections were all submitted by the individual States and may be derived from differing assumptions.

In summary, it is recommended that the point estimates of mobile source growth in Table 3-11 be used in analyses where nationwide average VMT growth rates are needed. Because there is considerable uncertainty in predicting how VMT will change in future years, upper and lower bound growth rates should be included in the analysis in addition to the point estimate. In adjusting the Table 3-11 growth rates to run sensitivity analyses, it is probably appropriate to assume that growth increases or decreases proportionately for all vehicle categories.

3.4 CONTROL EFFECTIVENESS

3.4.1 Mobile Sources

The effectiveness of future controls for mobile sources can be estimated using EPA's mobile source emission factor program (MOBILE2). This program accounts for both expected future emission levels by model year by vehicle type and the rate of retirement of existing vehicles from the present fleet. For use in a nationwide study, MOBILE2 emission factors for the base year and the projection year are calculated and used to determine an emission factor ratio. This emission factor ratio is simply expressed as:

$$\text{Emission Factor Ratio} = \frac{\text{Projection Year Emission Factor}}{\text{Base Year Emission Factor}}$$

This emission factor ratio is calculated separately for each motor vehicle type.

Despite slight differences in emission standards for California and high altitude areas, the technologies applied to reduce mobile source emissions are the same throughout the country. California and high altitude emission factors should be used where appropriate, however, using emission factor ratios computed from 49-state emission factors in a nationwide analysis will yield nearly the same results as using California specific emission factors.

The MOBILE2 emission factors program is used to account for controls mandated by the Federal Motor Vehicle Emission Control Program (FMVECP). If an estimate of the potential effectiveness of an inspection and maintenance (I/M) program is needed, the MOBILE2 program (U.S. EPA, 1978) can be used to generate this estimate. Because the emission factors including I/M credits are calculated within the MOBILE2 program, the effect of an I/M program is accounted for in rollback by changing the emission factor ratios.

I/M programs are required by the Clean Air Act Amendments (1977) if SIP's for ozone and/or CO cannot demonstrate attainment of the NAAQS by 1982. The original timetable for implementation of I/M programs was as follows (U.S. EPA, 1978):

June 30, 1979	Legal Authority for I/M Programs Required
December 31, 1981	Decentralized I/M Programs in Place
December 31, 1982	Centralized I/M Programs in Place

Although not all states met the June 30, 1979 deadline for enabling legislation, as of September 1, 1980, only two of the 29 states required to have I/M legislation did not have it. Taking into consideration the

fact that several areas already have operating I/M programs, it is reasonable to assume that on a nationwide average, all areas projected to not attain the CO and/or the O_3 standard by December 31, 1982 will have an I/M program operating beginning in 1982.

If changes in mobile source emission standards need to be evaluated, MOBILE2 can again be used to compute calendar year emission factors to account for these revisions. To change the emission standards for a vehicle type, new values for the zero-mileage emission rate and the emission factor deterioration rate per 10,000 miles must be input to MOBILE2. Changes in emission standards can and should be evaluated separately for each vehicle type. Again, emission factor ratios are used to estimate the impact of mobile source controls.

3.4.2 Stationary Sources

Estimating the effectiveness of stationary source controls for use in a nationwide analysis is not as straightforward as it is for mobile source controls because there are many more source types to deal with. Stationary source categories used in nationwide analyses are usually chosen so that source types with common growth rates and control efficiencies are grouped together. Therefore, the control efficiency used in the rollback or EKMA model is a weighted average based on control efficiencies for each source type. This process is further complicated by the fact that control efficiencies within each source type differ based on the type of fuel burned.

Of the three pollutants being discussed in this report, ozone is the only one that has been identified as having a significant stationary source influence at monitors measuring design values. Therefore, this section concentrates on providing control efficiency estimates for VOC sources. In nonattainment areas, the Clean Air Act Amendments require new and modified stationary sources to meet the lowest achievable emission

reduction (LAER) before a source can be located in an area or modified. Since EPA has not determined what constitutes LAER for stationary VOC sources, it should be assumed that new and modified sources will have to achieve a minimum level of control equal to reasonably available control technology (RACT).

For areas that fail to attain the standard with mobile source and new and modified stationary source control, existing sources will also be required to install RACT. RACT will vary among industries and may well vary among sources within an industry. RACT is defined as the lowest emission limit that a particular source is capable of meeting by applying control technology that is reasonably available considering technological and economic feasibility. Since economic feasibility is basically source specific, RACT may vary among sources in an industry. Since national assessments generally only consider broad categories of sources and do not consider the feasibility of RACT on individual sources, RACT is broadly defined here as technology available for application in categories of sources which will lead to adequate levels of control based solely on technical considerations. In actual practice, the reasonableness of technology for particular sources will be determined by State and local agencies based on technical guidance issued by EPA and depending upon economic and energy feasibility.

EPA has published guideline documents for VOC sources which assess the technology available for these sources. Based on these documents, estimates were made of the efficiency of RACT for major VOC sources. These estimates are shown in Table 3-12. As of January 1978, Control Techniques Guideline (CTG) documents had been issued for 15 stationary source categories. Legally enforceable RACT regulations must be submitted by the states on an annual basis in the January of the year following the publication of the CTG (Clean Air Act, 1977). Therefore,

TABLE 3-12

ASSUMED EFFICIENCY IDENTIFIED OF RACT FOR
VOC STATIONARY SOURCE CATEGORIES

Source Category and Sources Included*	Efficiency of RACT (%)	Assumed SIC
1. Chemical Manufacturing		28
• Organic Chemical Manufacturing Industry		
- Process Emissions	90%	
- Fugitive Emissions	80%	
- Storage and Loading Emissions	90%	
- Secondary Emissions	75%	
• Pharmaceutical Industry	95%	
• Paint Manufacture	90%	
• Rubber Industry	75%	
Weighted Average of RACT**	82%	
Current Emissions Affected by RACT***	79%	
Emission Reduction in Source Category Achievable with RACT	65%	
2. Petroleum Industry		29
• Gas and Crude Oil Production	90%	
• Petroleum Refining		
- Vacuum Jets	100%	
- Waste Water Separators	95%	
- Miscellaneous Sources	91%	
- Process Unit Turnaround	98%	
• Natural Gas and Gasoline Plants	96%	
Weighted Average of RACT**	95%	
Current Emissions Affected by RACT***	95%	
Emission Reduction in Source Category Achievable with RACT	90%	
3. Industrial Solvent Evaporation		39
Auto and Light Duty Truck Manufacturing	80%	
Flatwood Products	80%	

TABLE 3-12 (Continued)

ASSUMED EFFICIENCY IDENTIFIED OF RACT FOR
VOC STATIONARY SOURCE CATEGORIES

Source Category and Sources Included*	Efficiency of RACT (%)	Assumed SIC
Paper Coating	80%	
Fabric Coating	80%	
Wire Coating	90%	
Can Coating	80%	
Metal Furniture	85%	
Industrial Machinery	80%	
Commercial Machinery	80%	
Coil Coating	85%	
Fabricated Metal Products	80%	
Large Appliances	85%	
Small Appliances	80%	
Weighted Average of RACT**	80%	
Current Emissions Affected by RACT***	75%	
Emission Reduction in Source Category Achievable with RACT	60%	
4. Area Source Solvent Evaporation		
Dry Cleaning	65%	
Vapor Degreasing	55%	
Cold Cleaning	50%	
Graphic Arts	80%	
Adhesives	80%	
Cutback Asphalt Paving	100%	
Weighted Average	75%	
Current Emissions Affected by RACT	39%	
Emission Reduction in Source Category Achievable with RACT	30%	

TABLE 3-12 (Continued)

ASSUMED EFFICIENCY IDENTIFIED OF RACT FOR
VOC STATIONARY SOURCE CATEGORIES

Source Category and Sources Included*	Efficiency of RACT (%)	Assumed SIC
5. Petroleum Storage and Transport		29
Gasoline and Crude Oil Storage	75%	
Gasoline Bulk Terminals	95%	
Gasoline Bulk Plants	76%	
Weighted Average	80%	
Current Emissions Affected by RACT	100%	
Emission Reduction in Source Category Achievable with RACT	80%	
6. Gasoline Service Stations		29
Storage	90%	
Refueling	90%	
Weighted Average of RACT**	90%	
Current Emissions Affected by RACT***	83%	
Emission Reduction in Source Category Achievable with RACT	75%	
7. Fuel Combustion****		49
8. Other Industrial Processes****		39
9. Solid Waste****		--
10. Miscellaneous****		--

SOURCES: U.S. EPA, 1979
Peterson and Sakaida, 1978

TABLE 3-12 (Continued)

ASSUMED EFFICIENCY IDENTIFIED OF RACT FOR
VOC STATIONARY SOURCE CATEGORIES

* Sources included are those for which screening studies or guideline documents are being prepared. Many solvent evaporation sources and other industrial processes are not included because the sources have not been identified or control levels have not been defined.

** Represents weighted average of RACT for sources listed based on current national emissions for each category.

*** Represents the proportion of current national emissions for which RACT can be applied. Excludes emissions from source categories for which RACT control levels have not been identified and the residual emissions from sources which have already controlled to the RACT level.

**** RACT has not been identified for these source categories.

it is reasonable to assume that unless projections are being made for a year prior to 1982, that the RACT efficiencies in Table 3-12 can be used.

If the emission inventory in each region is grouped by the source categories identified in Section 3.1, the average emission reduction that could be achieved with the application of identified RACT must be determined for these categories. To do this, it is first necessary to derive the weighted average of the efficiency of RACT for the sources in each category for which RACT has been estimated. This weighted average takes into account each sub-category's relative contribution to current nationwide emissions, and the efficiency of RACT for each source. Therefore, the total emission reduction in each general source category is determined by multiplying the weighted efficiency of RACT for applicable sources by the percentage of emissions in the general source category which would be affected by RACT. The emissions affected by RACT include only those sources for which RACT has been identified and which have not already controlled emissions to the RACT level.

As Table 3-12 indicates, emissions from existing VOC sources can be reduced by 65 percent from the chemical manufacturing industry (industrial processes), 90 percent from the petroleum industry, 80 percent from petroleum storage and transport, 75 percent from gasoline service stations, and 60 percent from industrial surface coating operations. However, controls on identified area source solvent evaporation sources will reduce emissions from the total category by only 30 percent, since over half of the emission inventory results from sources which have not been identified and for which control levels have not been estimated.

Table 3-13 presents stationary source control efficiencies for CO and NO_x. While they will not be commonly needed for nationwide studies where design values are measured at urban monitors, they are included

TABLE 3-13

STATIONARY SOURCE CONTROL EFFICIENCIES

		CO*	NO_x **		
		RACT	RACT	NSPS	LAER
1.	External fuel combustion	90%	25%	33%	90%
2.	Internal fuel combustion	90	30	30	60-90
3.	Chemical manufacturing	--	--	--	
4.	Food/agricultural industry	--	--	--	
5.	Primary metal products	90	--	--	
6.	Mineral products	--	--	--	
7.	Petroleum industry	99	25	30-60	90
8.	Wood products	--			
9.	Industrial solvent evaporation	--			
10.	Other industrial processes	--			
11.	Solid waste disposal	99			
12.	Petroleum storage & transport	--			
13.	Gasoline service stations	--			
14.	Area source solvent evaporation	--			
15.	Miscellaneous	0			

* Source: PEDCo Inc., 1979.

** Source: U.S. EPA, 1979a.

because they might be useful in emission projections or special studies where stationary source influences are likely. CO control efficiencies in Table 3-13 are assumed to represent RACT. A wider variety of control options are available for NO_x, so three levels of control are identified for that pollutant in Table 3-13.

While the CO control efficiencies for RACT shown in Table 3-13 are currently available control technologies, the likelihood of their being applied to meet the current CO ambient standards is low. In most cases, CO SIP's concentrate on controlling mobile soures.

For NO_x, there are currently very few nonattainment areas. Therefore, RACT controls will only be applied to areas with annual averages greater than 100 $\mu g/m^3$. New Source Performance Standard NO_x controls for utility boilers were originally proposed in 1971 and should affect all boilers larger than 73 MW which have begun operation since 1976. This assumes a five year lag time between NSPS proposal date and boiler start-up date. For coal-fired utility boilers, a 0.6 lb/million Btu NSPS NO_x level was proposed in 1978. Assuming the five year lag time, boilers coming on-line after 1983 should be meeting the 0.6 lb/million Btu standard.

The NO_x control efficiencies listed in Table 3-13 for internal fuel combustion and petroleum industry sources under NSPS represent levels that new sources can attain with present control technology rather than proposed NSPS levels. Therefore, in a nationwide analysis, it should not be assumed that new sources in these categories will control to the NSPS levels shown in Table 3-13 unless NSPS's for NO_x are proposed.

3.5 SOURCE CONTRIBUTION FACTORS

As noted in the formulation of modified rollback (Equation 2-5), a source contribution factor (S_i) must be specified for each source category, i.e., mobile, stationary area and stationary point sources. This factor

is to account, in a very simplistic manner, for the effect of emission height and source-monitor separation on the contribution of that source category to the measured ambient concentrations. A factor of 1.00 implies that emissions are at or near ground level and near the monitor, and that they will have the greatest impact on air quality. Factors less than 1.00 imply that pollutants are emitted above ground level or at a considerable distance from the monitor, and because of a better opportunity for dilution, the emissions have a lesser impact on air quality than nearby ground level emissions. In a national analysis, these factors must represent some universal weighting of emissions for a specific category averaged over all sites. If sufficient data and resources were available, then the use of a more sophisticated dispersion model would provide these weighting factors directly. Of course, such detailed analyses are not usually within the scope of a nationwide analysis. Therefore, estimates of the source contribution factors must be based on extrapolations from previous site specific studies and engineering judgement.

3.5.1 Ozone

All sources of volatile organic compounds (ozone precursors) are generally considered to have a source contribution factor of 1.0 regardless of their distance from the design value monitor or of the height of emission. This assumption is made because ozone is a secondary pollutant requiring some time for formation in the ambient air, and is generally characterized as leading to a pervasive, as opposed to a "hot spot," air quality problem. The complexity of the chemical transformations (NMOC/NO_x to ozone), and the large geographic extent of ozone nonattainment areas, suggests that all VOC emissions should be considered collectively. In addition, height of release is not considered because ozone levels are assumed to be more dependent on total atmospheric loadings than on initial dilution at the point of emission. Recall that ozone is formed only after photochemical reactions with NMOC and NO_x have taken place, which is generally after the plume has been well mixed in the atmosphere and its initial height of release has become inconsequential.

3.5.2 Nitrogen Dioxide

Mobile and stationary area NO_x sources have traditionally been assigned source contribution factors of 1.0. The rationale for this selection follows from similar emission heights of these source categories and the annual averaging time imposed by the current NAAQS. The effect of the latter point is to "wash out" the effects of the spatial distribution of these sources. Therefore, no support for using a source contribution factor other than 1.0 is evident, provided that an annual average NAAQS is under consideration. Conversely, it is unclear what impact stationary point sources, which have been shown (see e.g., Chang, et al., 1980a) to make significant air quality contributions on a short term basis, have on NO_2 monitors in the existing network. However, none of the existing sites appears to have any significant impact from stationary point sources; they are dominated by mobile and stationary area sources. It follows then, that unless new information becomes available or new monitor sites are selected that are dominated by stationary point sources, that a source contribution factor of 0.0 should be used for point sources.

3.5.3 Carbon Monoxide

The selection process for source contribution factors for CO follows, very closely, that of NO_x. Again, the CO regulatory analysis has shown that, while stationary point sources can be shown to contribute to significant ambient concentrations, none of the CO monitors that currently indicate nonattainment are significantly impacted by stationary point sources. Hence, a weighting factor of 0.0 is assumed for stationary point sources. Note that the above discussion may not apply to all monitor sites nor to new sites.

Because of the availability of the SRI work mentioned in Section 2.2.1.1, an assessment of the relative impact of mobile and stationary CO area sources can be made. Recall that SRI examined, in detail, monitors in four areas: San Jose, Seattle, Phoenix, and Chicago.

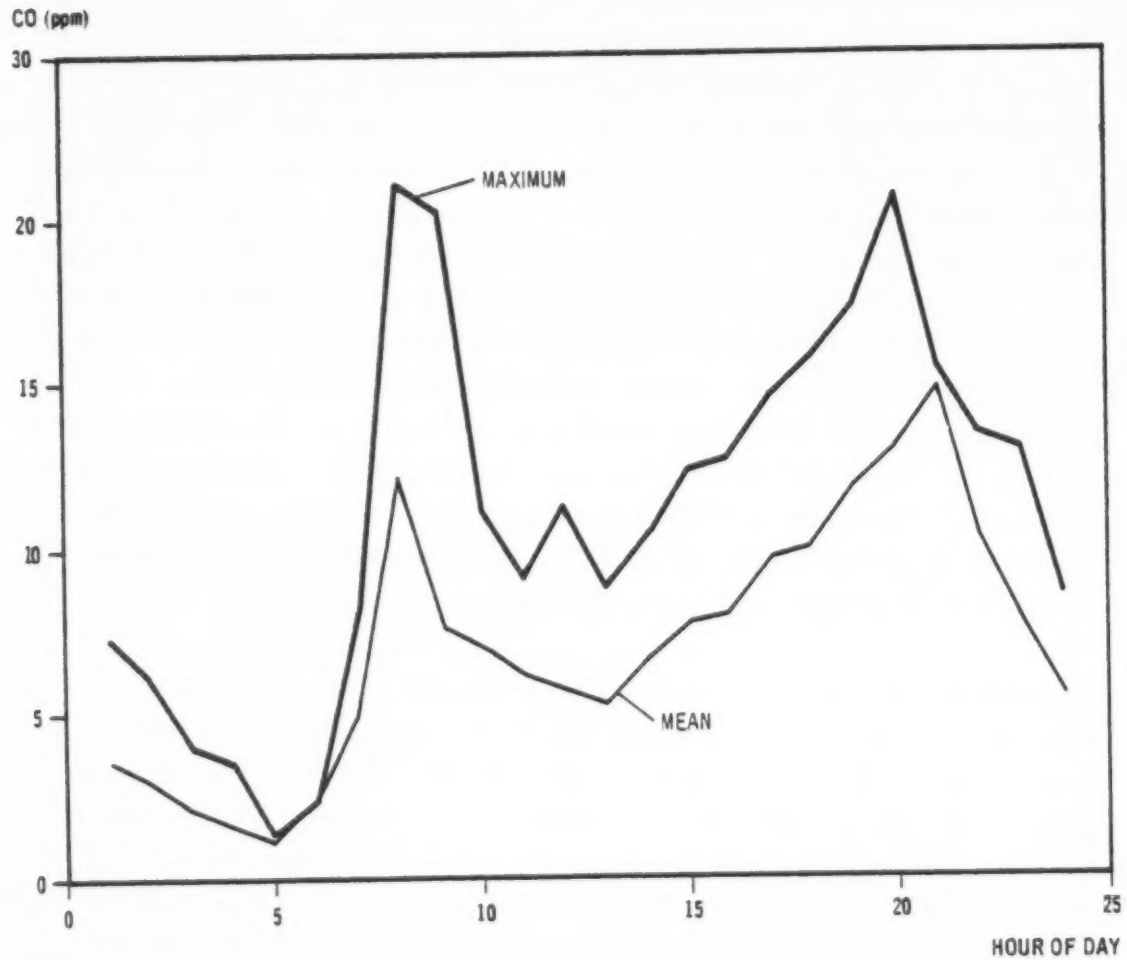
Monitoring data in San Jose show a correlation between traffic peaks and CO levels. This is illustrated in Figure 3-3 for one of the monitors closest to the intersection being studied. There is a sharp increase in CO concentration starting at 7 a.m. Concentrations drop rapidly after 9 a.m. and remain relatively constant through mid-day until they increase again around 3 p.m. Peak evening values occur at 8 p.m. The two sites most frequently upwind of the nearby roadways show the least evidence of the diurnal cycles. This is evidence that local contributions to CO are important at the downwind sites. Figure 3-4 shows the diurnal pattern of "local" CO contributions averaged across all monitors at the San Jose intersection. The local contribution is determined by subtracting the background concentration for that hour from the maximum observed concentrations. The local contribution to ambient CO levels during periods when the CO concentration was above 9 ppm (the 8-hour CO NAAQS) ranged from 62 to 98 percent and averaged 80 percent.

In Seattle, samplers were deployed on a one-way street in the Central Business District (CBD). Because the street was one-way, the bimodal traffic patterns observed in San Jose were not evident in Seattle. As can be seen from Figure 3-5, CO concentrations rise steadily through the day and peak between 5 and 7 p.m. Apparently, the street where the monitors are located is more heavily traveled outbound during the evening rush hour period than it is during the morning. Figure 3-6 shows the estimated percentage of locally generated CO at the Seattle site. As in San Jose, the maximum local contribution is determined by subtracting a background concentration for that hour from the maximum observed concentration. Although the local CO contribution usually ranges between

FIGURE 3–3

DIURNAL VARIATIONS IN CO CONCENTRATIONS OBSERVED BY HOUR OF THE DAY AT A SAN JOSE, CA ROADWAY MONITOR*

MAXIMUM AND MEAN ONE-HOUR AVERAGE MEASURED DECEMBER 8-15, 1977

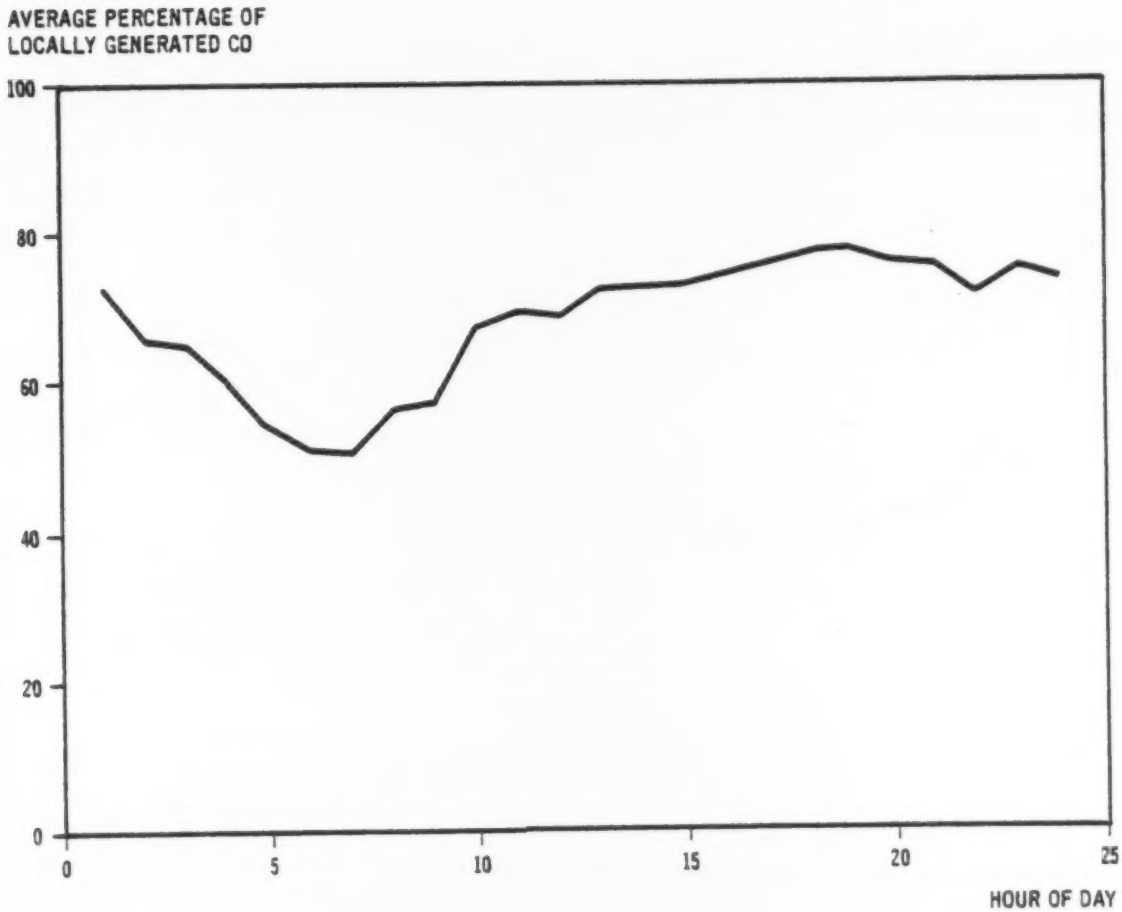


* Hourly values are averages of measurements during the one week monitoring period.

FIGURE 3–4

DIURNAL VARIATIONS IN CO CONCENTRATIONS DUE TO LOCALLY GENERATED EMISSIONS AT A SAN JOSE, CA INTERSECTION*

PERCENTAGE OF OBSERVED 8-HOUR (Running) AVERAGE MEASURED DECEMBER 8-15, 1977

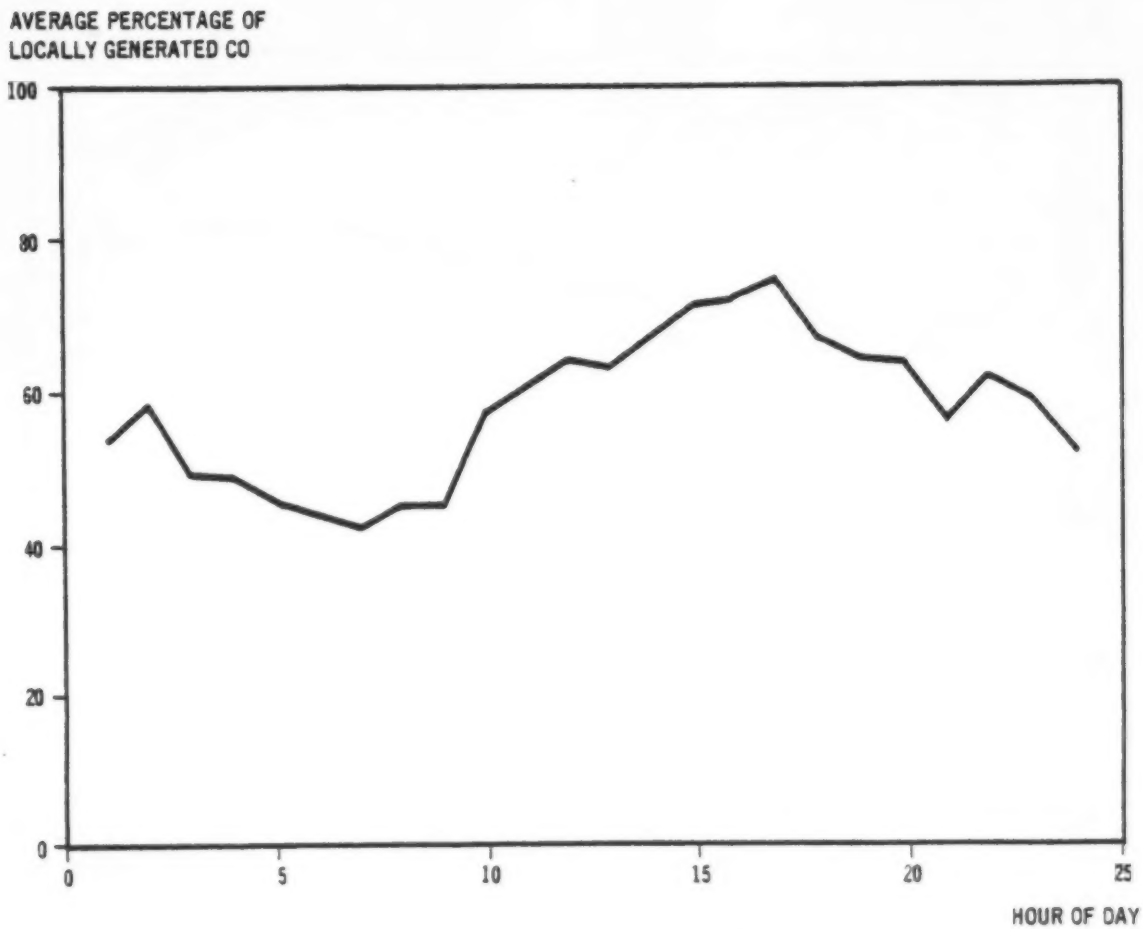


* Hourly values are averages of measurements during the one week monitoring period.

FIGURE 3-5

DIURNAL VARIATIONS IN CO CONCENTRATIONS DUE TO LOCALLY GENERATED EMISSIONS IN DOWNTOWN SEATTLE, WA *

PERCENT OF OBSERVED ONE-HOUR AVERAGE MEASURED JANUARY 11-18, 1978

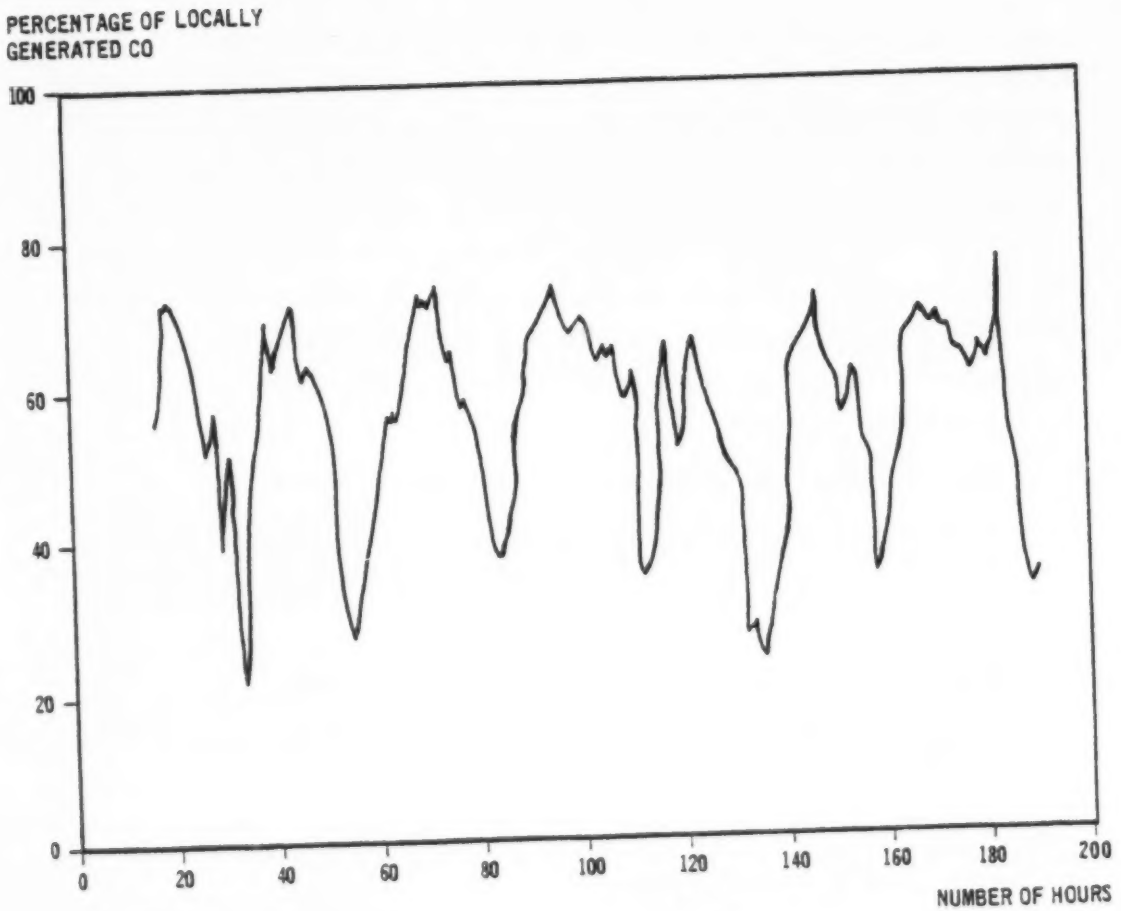


* Hourly values are averages of measurements during the one week monitoring period.

FIGURE 3–6

HOURLY VARIATIONS IN CO CONCENTRATIONS DUE TO LOCALLY GENERATED EMISSIONS IN DOWNTOWN SEATTLE

PERCENTAGE OF OBSERVED 8-HOUR (Running) AVERAGE MEASURED JANUARY 11–18, 1978



60 and 80 percent, at some hours in Seattle it is much lower. The "regional" contribution at times is as high as 70 percent. Therefore, the CO problem at these Seattle sites cannot be considered strictly "local" in nature.

CO concentration patterns in Phoenix were much different than those in the previous two cities. Although the study site in Phoenix was near a complex of government office buildings in the downtown area with dense traffic likely from 7 to 9 a.m. and 4 to 6 p.m., the highest CO concentrations were observed between 10 p.m. and 2 a.m.; a period with low traffic volume. Because high CO was observed at numerous monitors during this period, it was theorized that a recirculated air mass caused these readings. However, based on discussions with the meteorologist for the State of Arizona Bureau of Air Quality Control, SRI's conclusions about how these high levels occur may be somewhat misleading. In the winter months when high CO concentrations are most likely to be observed in Phoenix, the following pattern is predominant:

1. High CO emissions during 6 to 9 a.m. traffic peak.
2. From 10 a.m. on, upslope (westerly) winds predominate. There is intense surface heating which causes instability and promotes good vertical mixing. Therefore, no CO buildup is likely during the day.
3. High CO emissions during 4 to 6 p.m. traffic peak.
4. At approximately 6 p.m. an inversion forms. Winds continue from the west.
5. Sometime between 10 p.m. and midnight the wind direction changes, and downslope winds bring post 6 p.m. emissions back into the urban area causing high CO readings.
6. The inversion breaks up by 10 a.m. the next day.

Given this weather pattern, then, locally generated CO emissions end up producing the high observed values. The difference is that the

highest CO emission periods (morning and evening rush hours) are not the contributors to the highest ambient CO. Because CO emitted before 6 p.m. is not trapped by the inversion, it is unlikely to be carried back into the city late at night. Therefore, 6 p.m. to midnight emissions are the most directly related to high CO.

In a city with this type of situation, rollback is only applicable if the mix of sources contributing to the problem is the same as that in the emission inventory being used. If an air mass leaves and then returns to the downtown area, it is likely to be well mixed (within the inversion layer). Therefore, it is more likely in a city like Phoenix that non-mobile area sources or point sources can contribute to CO concentrations at the design value monitor if there is any transport.

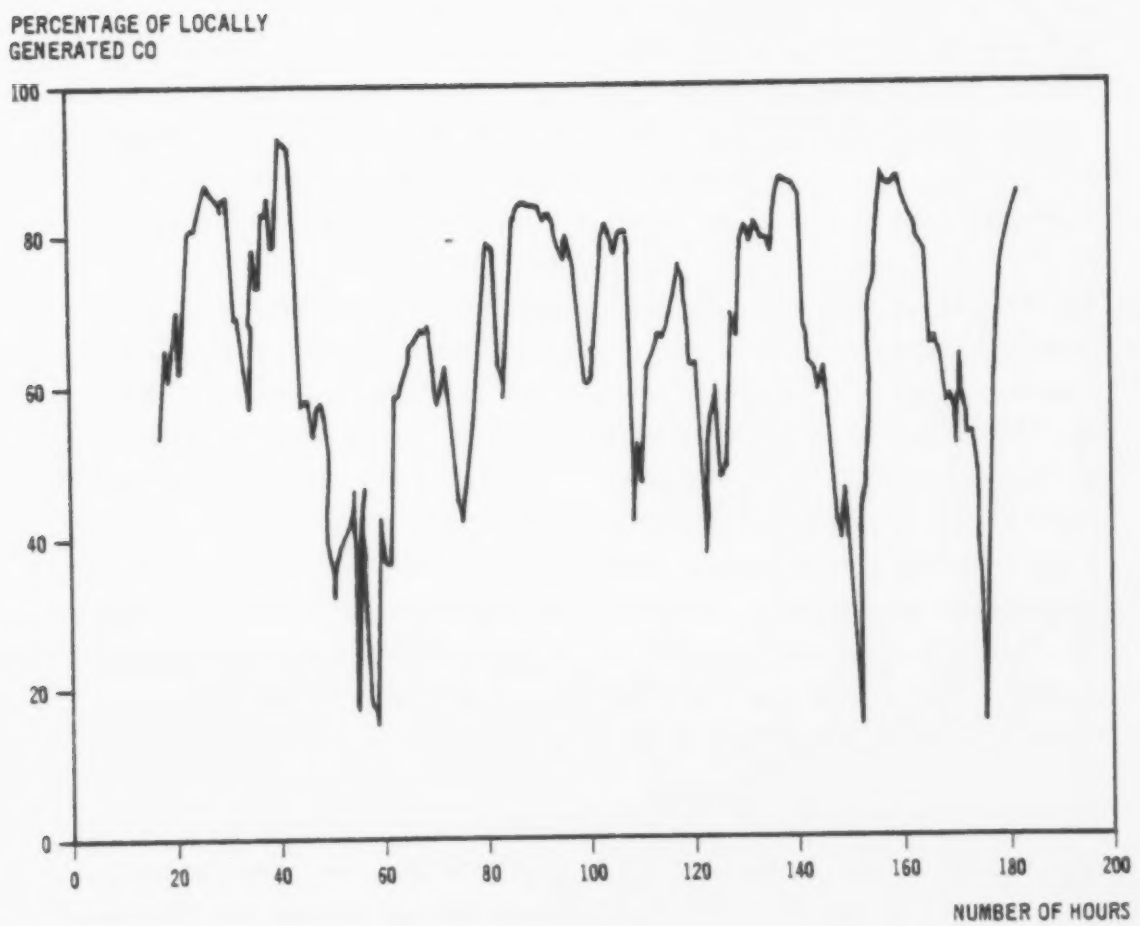
The monitor locations in downtown Chicago were representative of a "street canyon" situation, with nearby buildings all taller than ten stories. Figure 3-7 shows that while the local CO contribution is typically between 60 to 80 percent, it can be as low as 20 percent. Diurnal variations in CO concentrations were more evident at the "local" monitoring sites than at the "background" sites. Therefore, it can be concluded that to some extent these monitors reflect "local" changes in emissions. Because there were only two eight-hour CO standard violations during the Chicago study period, it is difficult to reach conclusions based on such a small sample. However, it should be noted that the "local" contribution to these two violations averaged 86 percent.

The monitoring data collected in Chicago are less representative of typical conditions in that city than the data from the other three cities. The CO concentrations observed in Chicago during the SRI study period were much lower than normal for the same period in previous years

FIGURE 3-7

HOURLY VARIATIONS IN CO CONCENTRATIONS DUE TO LOCALLY GENERATED EMISSIONS AT A CHICAGO, IL SITE

PERCENTAGE OF OBSERVED 8-HR (Running) AVERAGE MEASURED FEBRUARY 24-MARCH 3, 1978



as measured at a nearby SAROAD site. Violations of the 8-hour standard occurred approximately one percent of the time at the nearest SAROAD site in the first quarter of 1975. Concentrations at SRI's mobile laboratory did not even exceed 3 ppm one percent of the time during the test week. This difference is at least partially attributable to adverse weather conditions (snow) which reduced traffic during the study.

Because stationary CO area sources constitute major contributors to CO levels, they pose a perplexing problem. Based on emission height, they should probably be weighted the same as mobile sources. However, because of the short term averaging time of the NAAQS, averaging cannot be easily invoked (as with NO_2) to resolve spatial variability of sources. Area sources of CO will not, in general, be as heavily concentrated around the nonattaining monitors as mobile sources. Therefore, a weighting factor less than 1.0, but larger than 0.0 should be used. Because ratios of mobile to area source densities are not available around each site, some judgement concerning the level of the factor must be made. Traditionally, (see e.g., Chang, et al., 1980b) the area source contribution factor has been chosen to be 0.2. However, the value selected for this factor is usually not critical because stationary area souce CO emissions consitute only about 7% of the national total mobile and stationary area source inventory (EPA, 1980). Thus, an area source contribution factor of 0.20 can be used for national air quality assessments.

3.6 TRANSPORTATION CONTROL FACTORS

These factors are used to show the extent to which transportation control measures are expected to reduce mobile source emissions. They should only be used to account for measures designed to reduce VMT. Emission reductions due to the Federal Motor Vehicle Emission Control Program (FMVECP) and inspection and maintenance are accounted for in the mobile source control factors.

Transportation control measures (TCM's) are designed to change current travel patterns via either pricing or service incentives, or both. They are usually projects which involve a small investment of capital and attempt to induce immediate changes in travel behavior. Major capital projects like new freeways and subway systems which affect long-term travel are not TCM's. Through TCM's, an automobile driver may be induced to:

- Eliminate a trip
- Reduce the length of a trip
- "Double up" by carpooling
- Use transit.

Determining potential credits for TCM's for use in a nationwide analysis is difficult because there may be considerable variation in the transportation control plans among regions. Therefore, TCM's in one region may be designed to reduce emissions by only a few percent, while another region with a more extensive set of TCM's may expect their program to reduce emissions by 10 percent or more. Because of this variability, it is recommended that any projection analysis be run using more than one assumption about TCM credits to test the sensitivity of the results to changes in this variable. It is unlikely that TCM's will reduce mobile source emissions more than 10 percent, however.

Because transportation control plans are being continually changed through the SIP process, future nationwide analyses should take these changes into account. To the extent that transportation control plans are the same in different regions, a point estimate of TCM effectiveness can be made. Otherwise, a range of estimates should be used.

Determinations of credits for TCM's should be based on the most recent guidance from EPA's Office of Transportation and Land Use Policy (OTLUP).

REFERENCES FOR SECTION 3

Bureau of Economic Analysis. October 1977. "Population, Personal Income, and Earnings by State - Projections to 2000." U.S. Department of Commerce. Washington, D.C.

Chang, T.Y., Norbeck, J.M., and Weinstock, B. February 1980a, "NO_2 Air Quality-Precursor Relationship: An Ambient Air Quality Evaluation in the Los Angeles Basin," J. Air Poll. Control Assoc. 30:157.

Chang, T.Y., Norbeck, J.M., and Weinstock, B. January 1980b, "Urban-Center CO Air Quality Projections," J. Air Poll. Control Assoc. 30:1022.

Congress of the United States. February 1979. Changes in the Future Use and Characteristics of the Automobile Transportation System. Volume II: Technical Report. Office of Technology Assessment. Washington, D.C.

Decker, C.E., Worth, J.J.B., Ripperton, L.A., and Bach, W.D. January 1977. Ambient Monitoring Aloft of Ozone and Precursors Near and Downwind of St. Louis. EPA-450/3-77-009. Research Triangle Institute, RTP, NC. (Prepared for U.S. EPA, RTP, NC.)

Eaton, W.C., Decker, C.E., Tommerdahl, J.B., and Dimmock, F.E. April 1979. Study of the Nature of Ozone, Oxides of Nitrogen, and Nonmethane Hydrocarbons in Tulsa, Oklahoma. Volume II. Data Analysis and Interpretation. EPA-450/4-79-008c. Research Triangle Institute, Research Triangle Park, NC. (Prepared for U.S. EPA, RTP, NC.)

McNutt, B., Dulla, R., and Lax, D. March 1979. "Factors Influencing Automotive Fuel Demand." SAE Technical Paper Series. No. 790226. Congress and Exposition. Detroit, MI.

PEDCo Environmental, Inc. February 1979. Control Techniques and Costs for Carbon Monoxide Emissions. Interim Report No. 1. Cincinnati, OH.

Peterson, P.R. and Sakaida, R.R. December 1978. Summary of Group I Control Technique Guideline Documents for Control of Volatile Organic Emissions from Existing Stationary Sources. EPA-450/3-78-120. Pacific Environmental Services, Santa Monica, CA. (Prepared for U.S. EPA, Research Triangle Park, NC)

Trijonis, J. and Hunsaker, D. February 1978. Verification of the Isopleth Method for Relating Photochemical Oxidant to Precursors. EPA-600/3-78-019. Technology Service Corporation. Santa Monica, CA. (Prepared for U.S. EPA, RTP, NC.)

U.S. Department of Energy. October 1979. Industrial Sector Technology Use Model, Industrial Energy Use in the United States, 1979-2000. Volume I -Primary Model Documentation. DOE/FE/2344-1. Washington, D.C.

U.S. EPA. December 1977. Procedures for the Preparation of Emission Inventories for Volatile Organic Compounds, Volume I. EPA-450/2-77-028. RTP, NC.

U.S. EPA. January 1979a. Guideline for the Interpretation of Ozone Air Quality Standards. EPA-450/4-79-003. OAQPS No. 1.2-108. RTP, NC.

U.S. EPA. December 1979b. Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy Duty Engines. Office of Mobile Source Air Pollution Control. Ann Arbor, MI.

U.S. EPA. March 1980. 1977 National Emissions Report. EPA-450/4-80-005. RTP, NC.

U.S. EPA. January 1978a. Control Techniques for Nitrogen Oxides Emmisions from Stationary Sources-Second Edition. EPA-450/1-78-001. Research Triangle Park, NC. (Prepared by Acurex Corporation, Mountain View, CA).

U.S. EPA. August 1978b. User's Guide to MOBILE1: Mobile Source Emissions Model. EPA-400/9-78-007. Washington, D.C.

U.S. EPA. 1980. User's Guide to MOBILE2: Mobile Source Emissions Model. (In press) Ann Arbor, MI.

Wohl, M. and Martin, B.V. 1967. Traffic System Analysis for Engineers and Planners. McGraw-Hill Book Company. New York, NY.

4. STRATEGY EVALUATION CRITERIA

Indicators like percentage change in concentrations, number of exceedances of the NAAQS, and number of regions experiencing NAAQS violations are typically used in nationwide studies to compare the effectiveness of alternative motor vehicle emission standards or other control programs. The usefulness of each of these indicators in predicting differences among control scenarios is discussed in this section. In addition, some less frequently used indicators such as concentration frequency distributions, populations at risk, and number of unhealthful days will be presented and critiqued. The indicators discussed in this section are important because they are the criteria by which alternative scenarios are judged.

4.1 PERCENTAGE CHANGE IN POLLUTANT CONCENTRATION

Calculating the percentage change in air quality between the base year and the projection year is accomplished using equation (4-1):

$$\frac{\text{Projection Year A.Q. - Base Year A.Q.}}{\text{Base Year A.Q.}} * 100\% = \text{Percentage Change} \qquad (4\text{-}1)$$

This computation is made for each area in the nationwide sample and then the specific area values are averaged to determine a nationwide average.

This measure essentially provides a weighted average of the effectiveness of emission controls. Emissions are weighted by the source contribution factors. The average percentage change in air quality equals the average percentage change in emissions if the source contribution factors are all equal to one, and there is no background.

This indicator is useful if the purpose of the analysis is to compare the effectiveness of different control strategies like different auto emission standards. Then, knowing the weighted average effectiveness of the controls vis-a-vis other source types is important. It is a good indicator to use in a nationwide analysis where a sample of regions is chosen to be representative of the entire U.S. However, for a regulatory analysis where attaining/not attaining a standard is of most interest, its usefulness is limited.

The significance of a percentage decrease in pollutant concentration depends on the base year ambient levels and their magnitude in relation to the NAAQS. For example, a two percent reduction in ambient levels may be sufficient to bring a region that is already close to the standard into compliance. However, in a region with pollutant levels much higher than the standard, two percent would be a totally inadequate reduction.

4.2 NUMBER OF EXCEEDANCES OF THE NAAQS

More than one method can be used to project the number of exceedances of the NAAQS. The basic procedure is to choose a frequency distribution (e.g., exponential) which has been shown to be representative of the pollutant in question and use this distribution to estimate the number of violations from the projected concentration for a given sampling time. The most straightforward manner to apply this technique is to use a single distribution for all areas. The more complex alternative is to project a separate distribution for each region.

An example where a distribution was used to predict the number of NAAQS violations is in a past analysis of alternative automotive emission standards. (U.S. EPA, 1979).

In this analysis, violations of the ambient O_3 standard were estimated using an exponential distribution for O_3 concentrations. The exponential distribution had the form:

$$F(C) = 1 - \exp(-C/\bar{C}) \qquad (4\text{-}2)$$

where:

$F(C)$ = the fraction of values less than or equal to the concentration C

$\bar{C}$ = the mean of the observed concentrations

Hourly O_3 data were used to determine the design value and the mean for the base year. These values were then projected to future years using the rollback model, and used in equation (4-2) to estimate the number of hours that the standards would be violated.

Other researchers have confirmed the use of the exponential distribution as a good descriptor of the upper tail of most ambient concentration distributions (Breiman, Gins and Stone, 1978) (Curran and Frank, 1975). These references are particularly useful because they concentrate on predicting peak air pollution concentrations. In addition, it should be noted that the one-parameter exponential distribution is readily adapted to the rollback formulation where only the peak concentration value is available.

Because this measure compares ambient values to the NAAQS, it provides some information on the potential health risk of exposures to high pollutant levels. Presumably, the greater the number of violations, the greater the health risk. However, there are some uncertainties involved in estimating the number of ambient standard violations. One is that the distribution selected as representative of the data in the base year is accurate. Another is whether the distribution of air quality values in the base year will be the same in future years. Because control

strategies may be focused on the highest recorded level, the distributions may typically change over time. However, if the sample of cities used in an analysis is large enough, and the errors in estimating the number of exceedances are randomly distributed between cities, the projected nationwide number of violations should be a valuable indicator for comparing alternative control options.

4.3 NUMBER OF REGIONS WITH AMBIENT LEVELS GREATER THAN THE STANDARD

This is a straightforward number to calculate, but an important measure to use in comparing control strategies. It is especially important in determining the potential control costs to achieve a standard and may be used as a surrogate for exposure. In the recent regulatory analyses, this indicator was extremely important because a change in the ambient standards directly affects costs to industries and consumers in areas which must impose controls to meet those standards. The steps in the regulatory analyses were:

- Use base year monitoring data to determine design values
- Project design values to the future year of interest
- Compare projection year design values to ambient standards
- For areas with values greater than the standard, impose controls to bring them into compliance
- Calculate the cost of meeting the ambient standard.

Therefore, estimating whether a region will or will not comply with an ambient standard is crucial in evaluating needed nationwide control strategies and their associated costs. While this is a useful measure in a nationwide analysis, the use of rollback or the standard EKMA isopleths to predict attainment or nonattainment by any single area is inappropriate. Control strategies in specific areas may be far different than those assumed as a nationwide average.

4.4 OTHER STRATEGY EVALUATION CRITERIA

The approach used for evaluating the effectiveness of expected emission reductions in the next 10-20 years by the Council on Environmental Quality (CEQ, 1976) in its annual reports is somewhat different than that typically used in projection analyses. Instead of using a design value to judge attainment or nonattainment of a standard, the CEQ projects the distribution of concentrations. This distribution shows both absolute concentration intervals and the number of days in a year with maximum concentrations in those intervals. This technique assumes a 1:1 relationship between emissions and air quality reductions. Essentially, expected reductions in emissions are accounted for by shifting the distribution downward according to the percentage reduction in emissions assumed.

Another CEQ indicator for measuring air quality trends is the number of unhealthful days. The 1979 CEQ Annual Report uses the Pollutant Standards Index (PSI) for each city to determine the number of days with unhealthful air. In this CEQ report, they use PSI data from 1975-1977 to rank SMSA's by the number of "unhealthful" and "very unhealthful" days. For each county with monitoring data, CEQ multiplies the county population by the number of days on which the levels of each of the criteria pollutants exceeded the primary NAAQS. This yields the number of person-days of exposure in the county for the year.

The chief advantage of these techniques is that they present more than just the expected change in the design value for a region. However, when considering them for use in a nationwide analysis, this advantage is outweighed by the amount of effort to assemble the data for each region.

4.5 CONCLUSION

The current version of the modified rollback computer program used by EPA uses three summary statistics as indicators of the nationwide dif-

ferences in control options. They are the projected average percentage change in air quality, the number of cities with concentrations above the standard, and the total number of violations. Each one of these indicators is useful for comparing control options, but some indicators should receive more emphasis than others depending on the type of analysis being performed. For example, if different motor vehicle emission standards are being compared, the average percentage change in air quality is probably the most useful. Alternatively, if a regulatory analysis is being performed, the number of cities above the standard is the most important indicator because costs for controls are only incurred in areas that violate the standard. In both cases, the total number of violations indicator provides useful additional information about the extent of high concentrations in the projection year.

In the CEQ reports, the indicators provide some additional information when compared with the current rollback output, but with the exception of including county population estimates to the data base, they are only marginally useful and would be extremely time consumptive to include in a rollback format.

REFERENCES FOR SECTION 4

Breiman, L., Gins, F. and Stone, C. November 1978. Statistical Analysis and Interpretation of Peak Pollution Measurements. Technology Service Corporation, Santa Monica, CA (Prepared for U.S. EPA, Research Triangle Park, N.C.)

Council on Environmental Quality. September 1976. Environmental Quality - 1976. The Seventh Annual Report of the Council on Environmental Quality. Washington, D.C.

Council on Environmental Quality. December 1979. Environmental Quality - 1979. The Tenth Annual Report of the Council on Environmental Quality. Washington, D.C.

Curran, T.C. and Frank, N.H. 1975. "Assessing the Validity of the Lognormal Model when Predicting Maximum Air Pollution Concentrations" Paper No. 75-51.3, 68th Annual Meeting of the Air Pollution Control Association, Boston, MA.

U.S. EPA. November 1979. "Data Assumptions and Methodology for Assessing the Air Quality Impact of Proposed Emission Standards for Heavy-Duty Vehicles." OAQPS, RTP, NC.

5. SUMMARY AND CONCLUSIONS

5.1 APPLICABILITY OF ROLLBACK AND EKMA

This study recommends methodologies appropriate for evaluating the nationwide impact of emission control strategies on ambient levels of CO, NO_2 and O_3. These methodologies are not recommended for SIP analyses of specific urban areas. They are particularly appropriate for evaluating mobile source control strategies. Therefore, they apply to the mobile source related pollutants. These methods use a sample of regions with ambient data indicating a standards violation or the potential to exceed the standard in the analysis. While emissions and air quality data specific to each area are used, other assumptions about control effectiveness, growth in new sources, retirement of existing sources, and source contributions are made on a nationwide average basis.

CO and NO_2 air quality projections are performed using the Modified Rollback Model (de Nevers and Morris, 1975) to relate pollutant emissions and ambient concentrations. This model assumes that the ambient concentration of a pollutant is a linear function of pollutant emissions within a specified geographical area. Therefore, a change in CO or NO_x emissions is assumed to result in a proportional change in CO or NO_2 concentrations.

Ozone air quality projections are made using the Empirical Kinetic Modeling Approach (EKMA) (U.S. EPA, 1977). EKMA utilizes a set of ozone isopleths which depict maximum afternoon concentrations of ozone downwind from a city as a function of initial (i.e., morning) concentrations of NMOC and NO_x, VOC and NO_x emissions occurring later in the day, meteorological conditions, reactivity of the precursor mix, and concentrations of ozone and precusors transported from upwind areas.

However, in the version of EKMA typically used in nationwide studies, NO_x levels are assumed to remain constant. Therefore, only reductions in VOC emissions are assumed to affect O_3 concentrations. The $NMOC/NO_x$ ratio assumed for each area affects the percentage reduction in O_3 attributable to a given reduction in VOC emissions. Therefore, area specific ratios should be used when available. A default value of 9.5:1 is used in areas with no monitoring data.

When comparing models like rollback and EKMA with complex dispersion models, the most important difference is in determining the source contributions. The extent to which a reduction in emissions will produce a reduced pollutant concentration for a given source category depends on source-receptor distance, atmospheric stability, wind speed and effective stack height. The source contribution factors used in a rollback application are determined from monitoring and modeling data. A source contribution factor is determined separately for each source type which contributes significantly to measured concentrations. Then, once the source contribution factors are chosen, all strategy evaluations become rollback analyses.

The main advantage of using rollback is its computational and resource economy. There are several limitations associated with rollback however. The most significant are:

1. Lack of model validation

2. The assumed linear relationship between emissions and air quality. Deposition, agglomeration and chemical reaction could invalidate the linear assumption.

3. The current base year concentration may not be known based on coverage of the monitoring network.

4. The growth factor used assumes all other parameters remain unchanged, i.e., all sources grow equally and their spatial distribution remains constant.

5. Simple and "modified" rollback assume that the meteorological conditions occurring when the design value was measured are the same in the projection year.

6. Very simplistic treatment of source-receptor relationships.

7. Simple rollback assumes all sources emit at the same height and "modified" rollback assumes sources within certain categories emit at the same height.

8. Estimates can only be made for existing monitoring sites.

It should also be noted that the rollback formulation is inherently designed to estimate changes in air quality concentrations based on current air quality and assumed background levels resulting from emission changes. Therefore, it should be used to examine relative differences between control strategies rather than absolute levels. Likewise, EKMA isopleths are most properly interpreted when used in a relative rather than an absolute sense.

5.2 SUGGESTED METHODOLOGIES FOR COMPILING MODELING DATA

5.2.1 Emission Inventories

The National Emissions Data System (NEDS) is recommended for use in compiling emission inventories for nationwide studies. NEDS is the only source which uses consistent inventorying procedures and compiles data in a common set of source categories. NEDS inventories are typically provided on a county or AQCR basis. After study of the characteristics of the three mobile source related pollutants, it is recommended that county inventories be used for CO and NO_2 analyses, and AQCR inventories be used for O_3 analyses. Although CO is predominately a microscale problem, county inventories are the most detailed included in NEDS, and it would be impossible to find a consistent inventory area smaller than a county for which information would be available on a nationwide basis.

The source category groupings recommended for use in a nationwide study are shown in Tables 3-3, 3-4, and 3-5.

5.2.2 Design Values

The design value is defined as the concentration that must be reduced to the level of the standard for an area to be in attainment. In using ambient monitoring data in national strategy assessments, design values are usually chosen to correspond to the form of the standard for each pollutant and for a time period consistent with the emission inventory. Design values for the three pollutants considered in this report are usually chosen as follows:

- Carbon Monoxide -

  The highest second high eight-hour average in the three year period encompassing the emission inventory base year.

- Ozone -

  The one-hour average measured in the three year period encompassing the emission inventory base year which is expected to be exceeded an average of once per year (See Table 3-6).

- Nitrogen Dioxide -

  The highest annual average measured in the three year period encompassing the emission inventory base year.

5.2.3 Growth and Retirement Rates

5.2.3.1 Stationary Sources

Future changes in industrial activity can be accounted for by a combination of growth and retirement rates. Growth and retirement are differentiated because regulations affecting new sources differ from those affecting existing sources. Therefore, different control assumptions are identified for each. Growth rates and controls are applied to estimate new source emissions. Retirement rates are applied to estimate how emissions from existing sources will decrease.

When applying the growth and retirement rates listed in Section 3, it should be noted that these are national averages based on broad stationary source categories, which are judged to be sufficient for a national scale analysis. They may not be representative of a particular urban area.

5.2.3.2 Mobile Sources

Predicted growth in vehicle miles traveled (VMT) serves as a surrogate for estimating the true growth rate in mobile source emissions. However, growth in VMT is difficult to predict for two reasons. One is the uncertainty in how changes in fuel prices will affect demand for gasoline and travel. The second is identifying how VMT will change in the areas that specifically affect high pollutant levels. Therefore, because of the considerable uncertainty in predicting VMT over a 10-20 year period, it is advisable to use a range of possible growth rates to judge the sensitivity of the modeling results to changes in this factor.

It should also be noted that the growth rates in Section 3 may differ from the area specific VMT growth rates used in state and local analyses.

5.2.4 Control Effectiveness

The effectiveness of future controls for mobile sources can be estimated using EPA's mobile source emission factor program (MOBILE2). This program accounts for both expected future emission levels by model year by vehicle type and the rate of retirement of existing vehicles from the present fleet. MOBILE2 can also be used to evaluate the effectiveness of I/M programs.

Estimating the effectiveness of stationary source controls for use in a nationwide analysis is not as straightforward as it is for mobile source controls because there are many more source types to deal with. Stationary source categories used in nationwide analyses are usually chosen

so that source types with common growth rates and control efficiencies are grouped together. Therefore, the control efficiency used in the rollback or EKMA model is a weighted average based on control efficiencies for each source type.

Estimates of control efficiencies for stationary sources of VOC detailed in Section 3 are taken from the Control Techniques Guideline (CTG) documents published to date. As new CTG documents are published, the numbers in Table 3-12 can be updated. Control efficiencies for NO_x and CO stationary sources can be updated through new editions of their respective Control Techniques Documents (CTD's).

5.2.5 Source Contribution Factors

Source contribution factors are an attempt to account for the effect of stack height and source-monitor separation on the contribution of each source category to measured ambient concentrations. A factor of 1.0 implies that emissions from that source category are typically at or near ground level and near the monitor measuring the design value. Factors less than 1.0 imply that pollutants are emitted above ground level or at a considerable distance from the monitor, and because of a better opportunity for dilution, the emissions have a lesser impact on air quality than nearby ground level emissions.

All ozone precursors are generally considered to have a source contribution factor of 1.0. This assumption is made because ozone is a secondarily formed pollutant and is generally characterized as leading to pervasive, as opposed to "hot spot", air quality problems. For NO_2, point sources are not significant contributors to annual average concentrations measured at urban monitors. Therefore, they are assigned a source contribution factor of zero. Mobile and other area source emissions are assumed to contribute 100 percent to ambient NO_2. Similarly for CO, it is assumed that point sources have zero contribution at design value monitors. A

source contribution factor of 1.0 is recommended for mobile sources, and a 0.2 factor is recommended for stationary area sources. The 0.2 source contribution factor is based largely on the typical distance of CO area sources from urban CO monitors in comparison with mobile sources.

5.2.6 Transportation Control Factors

These factors are used to show the extent to which Transportation Control Measures (TCM's) are expected to reduce mobile source emissions. They should only be used to account for measures designed to reduce VMT. Emission reductions due to the Federal Motor Vehicle Control Program (FMVCP) and I/M are accounted for in the mobile source control factors.

Determinations of credits for TCM's should be based on the most guidance from EPA's Office of Transportation and Land Use Policy (OTLUP). Because there may be considerable variation in the transportation control plans among regions, it is advisable to model a range of TCM credits rather than one point estimate.

5.3 STRATEGY EVALUATION CRITERIA

The current version of the modified rollback computer program used by EPA uses three summary statistics as indicators of the nationwide differences in control options. They are the projected change in air quality, the number of cities with concentrations above the standard, and the total number of violations. Each one of these indicators is useful for comparing control options, but some indicators should receive more emphasis than others depending on the type of analysis being performed. See Section 4 for more details about the interpretation of these factors.

REFERENCES FOR SECTION 5

deNevers, N. and Morris, J.R. 1975. "Rollback Modeling: Basic and Modified", J. Air Poll. Control Assoc. Volume 25, No. 9.

U.S. Environmental Protection Agency. November 1977. Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors. EPA-450/2-77-021a. Research Triangle Park, NC.